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Semi-Popular Articles

Corrections

On page 114 of the preceding issue of ECONOMIC BOTANY, *Yucca baccata* should read *Yucca elata*, and on page 127 the creosote bush (*Larrea divaricata*), not the greasewood bush (*Sarcobatus vermiculatus*), should be reported as the source of nordihydroguaiaretic acid.

See page 330 of this issue for another correction.

Milkweed—*A War Strategic Material and a Potential Industrial Crop for Sub-marginal Lands in the United States*

In 1943 the U. S. Federal Government erected a milkweed floss- and seed-extracting plant at Petoskey, Michigan, the only one of its kind in the world, and in one year this plant furnished to the armed forces two million pounds of milkweed floss that was used in lieu of kapok from Java in the manufacture of lifesaving equipment. Two million pounds of seed and tons of fibers were by-products as potential commercial sources of oil and cellulose, respectively.

BORIS BERKMAN

President, Milkweed Floss Corporation of America, Chicago, Illinois

Introduction

Theories of today may be the stepping stones to the facts of tomorrow, and alleged facts of today may be proven unsound theories in the light of future discoveries. As examples, one has only to recall that heavier-than-air craft, splitting of the atom, radio and television, all established facts of today, were unheard of 50 years ago, or were regarded at that time only as fantastic theories. On the other hand, rigid dogma of yesterday, which considered molds only as toxic and undesirable factors in decomposition, must, in the light of penicillin and other antibiotics, be discarded today as unsound and unscientific.

The history of the utilization of plants for the benefit of the human race is full of similar evidence that it takes a long time for new thoughts, though they embody definite improvements, to be accepted, especially if those thoughts contradict old established concepts of usefulness and desirability. The corn plant in North America, highly esteemed as a valuable food by the native Indians, was considered undesirable and had a hard time becoming accepted by the early white settlers of North America. Only 30 years ago the soybean was ridiculed in the United States, and the probability that it would ever become a major crop was negligible. At present it is one of our most important crops, the source of countless food and industrial products.

In the light of these historical precedents, the concept of the milkweed plant as a potentially valuable raw material for several industrial products, as implied in the title to this article, should not be discarded lightly. Use of the floss as an emergency strategic material during the recent war has already established the plant's potential value. This use and the possibilities of other industrial utilization are discussed in this article.

Utilization Prior to the Twentieth Century

The milkweed family, the Asclepiadaceae, contains a large number of fiber-producing herbaceous plants native to different portions of the world and varying from shrubby growths, a few feet in

height, to the giant forms of India that attain ten feet or more. More than 20 species are native to the United States, probably the commonest and best known of which is *Asclepias syriaca* L. This species grows wild in Canada and over wide sections of the United States, and is as well known in portions of South America and of southern Europe. Among specimens of it in the old Glover Museum of the United States Department of Agriculture there are some fine examples from Brazil which were most carefully prepared, seeming to show that the value of the plant was recognized in that country. According to one of the old authorities: "an early knowledge of the fibre of silkweed caused the introduction into Europe, where it has fully become a cultivated plant, while in its own country but little is known of its true value" (9).

Among several other fiber-producing species of the Asclepiadaceae, and found chiefly in the Old World, is *Marsdenia tenacissima,* W & A, or Rejmahl Bowstring Creeper, the source of the jeete fiber of India. This twining shrub grows in the Rejmahl hills of that country, in dry and barren places, and the fibers of the bark are used by the mountaineers for making bowstrings. The fibers are reported to be not only beautiful but strong and durable. In Roxburg's test of twine (8) made from jeete, he found that in the dry and wet states it bore strains of 248 and 343 pounds, respectively, whereas comparable figures for hemp were only 158 and 190. The fiber has long been widely employed in its native land for making nets and is not liable to injury by being kept in water.

The prehistoric Indians of North America used the bast fibers of milkweed for textile purposes. *Asclepias syriaca* was the most widely employed, and clothing found in ancient burial places, 1,000 years old, were made from it. Whitford (47) attributes such use to the fibers of four species, *A. tuberosa* L., *A. pulchra* Ehrh., *A. incarnata* L., and *A. syriaca* L. Other Indian tribes of North America relied upon the milkweed plant for food and medicinal benefits. Buds of *Asclepias incarnata* L. were dried and stored for winter use by the Menominee Indians, or were made into soup with deer broth, or added to cornmeal mush. The leaves and young shoots of *A. speciosa* Torrey were boiled with meat by the Hopi Indians of Arizona; in Montana and California the flowers were eaten boiled or raw; and in Wisconsin, Minnesota, Montana and Wyoming the seeds were eaten raw and the buds consumed with meat or boiled with soup. In New Mexico *A. involucrata* Eng. was similarly used for food. The Chippewa Indians used the flowers of *A. syriaca* in a stewed form, and the Iroquois ate young green fruits, young sprouts and buds.

Kalm (20) says that the French in Canada used the tender spring shoots of milkweed, preparing them like asparagus, and that they also made a very palatable sugar from the flowers. Tremont (42) found the Sioux Indians of the upper Platte River eating young pods and boiling them with buffalo meat. Jeffery, referring to Canada (42), says: "What they call here the cotton tree is a plant which sprouts like asparagus to the height of about three feet and is crowned with several tufts of flowers; these are shaken early in the morning before the dew is off of them, when there falls from them, with the dew, a kind of honey, which is reduced to sugar by boiling".

Natives of Tanganyika use the bast fibers from the stalks of *A. semilunata* N.E.Br. for fishnets (6), and in the central part of India the bast fibers of *A. gigantea* L. have been employed by the natives for textile purposes. Gleditsch in Germany used the floss of milkweed for padding, and in 1754 he reported

the results of experimental work with *Asclepias* to the Academy of Science in Berlin. LaRouviere in France produced cloth from the floss at about the same time (27), and in 1811 Baron Jacquin published a detailed description of the milkweed plant. Several ventures in the cultivation and possible utilization of *A. incarnata* and *A. syriaca* were made in Canada about the middle of the last century, along with similar work in Russia (21, 23).

Fig. 1. The milkweed-processing plant of the Milkweed Floss Corporation of America, built by the U. S. Federal Government in Petoskey, Michigan, in 1943 at a cost of $225,000, to furnish milkweed floss to the armed forces during World War II for use by them principally in life preservers. It produced more than two million pounds of the floss for this purpose in the one year of its operation.

Utilization in the Twentieth Century exclusive of the Floss

It soon became apparent to twentieth century investigators of the utilitarian qualities inherent in milkweed that utilizing the products of these plants in the primitive manner of a century ago precluded successively growing milkweed as a regular and economically profitable crop. Only by taking advantage of chemical and mechanical sciences could this crop be converted into products, such as floss, synthetic fibers, oil, wax, rubber and plastics, that would command profitable prices and could be utilized as raw material for important industrial enterprises. To that end there has been a revival of interest in the United States, Canada and Russia during recent years in the chemurgic possibilities of milkweed. This revival is attributable not only to the application of chemistry to the utilization of agricultural products in general, but also to improvements in the processing of milkweed floss, as will be described later in detail.

In Russia this revival of interest has been devoted to the extraction of oil and fat from the seeds, and of latex from the leaves and stalks (25, 30, 31). Stepanov (38), for instance, analyzed milkweed as an oil- and rubber-producing plant, and reported that "oil from the seeds of milkweed can be used *a*) for the manufacture of liquid soap, for which there is a large demand in the textile industry; *b*) for the production of siccatives; *c*) for the production of fats by hydrogenation. Our rubber industry should put an end to its persistent understimation of this plant as a source of rubber. Cultivation of this plant should yield thou-

sands of tons of natural rubber, to be mixed with our synthetic rubber. Milkweed should occupy a proper place among our valuable technical plants". He mentions the possibility of utilizing the stems in the paper industry, but does not say anything about the floss.

In Canada we find the same trend of thought, especially during World War II when a great deal of work was done at the Central Experimental Farm in Ottawa on the propagation and cultivation of the plants, on germination of their seeds, *etc.* Some of the best cultivated fields of *Asclepias incarnata* and *A. syriaca* observed by the author have been in Ottawa. In 1943 over 500 acres of land in Peterborough County as well as at Ottawa were seeded by the farmers, subsidized by the Canadian government. A cooperative research program, involving various government departments and universities, on the extraction of resin rubber gum from the common milkweed has been under way in Canada since 1942. Based on a series of batch operations worked out in the laboratory, a pilot plant has been built in Ottawa that is capable of rapid extraction of substantial amounts of gum. The design includes provision for ultimate integration to continuous operation. A 15–85 milkweed gum CR.s mixture in a tire tread compound resulted in an improvement in tack, an increase in tear resistance, a drop in both tensile strength and modulus, an increase in elongation at overcure, a drop in resilience, an improvement in the heat embrittlement figure, and a considerable improvement in flex life (12, 14, 32, 46).

It is apparent from several writers (*e.g.*, 12, 13, 14, 46) that the rubber possibilities of *Asclepias* have been predominant in the minds of Canadian scientists, and that the same tendency has prevailed in the U. S. Department of Agriculture and among independent investigators (2, 7, 15, 17). Edison and Ford, among the latter, were interested primarily in latex, and avoided investigating any other utilitarian possibilities of milkweed. All these investigators have been confronted by one basic fact which is of prime importance in the usefulness of milkweed as a profitable rubber-producing source, namely, that the rubber content of milkweed is not sufficiently high to make the growing of it exclusively as a source of rubber a sound commercial venture. Other products, producing additional income, must be obtained before it can seriously be considered as an industrial crop. Among such other products is the floss attached to the seeds within the seed pods, but before the utilization of that floss could be developed it was very apparent that a mechanized method of separating the floss from the seeds and pods would have to be developed, for only then could the plants produce enough revenue to make their production and processing profitable.

Milkweed Floss as a Strategic Material of World War II

The incentive to develop such a method of mechanically isolating the floss from milkweed pods was provided by the exigencies of World War II. Previous to the seizure of the Dutch East Indies in 1942 by the Japanese, the world's foremost commercially important stuffing material for life preservers, life cushions and similar articles was kapok, imported by the United States in large quantities, chiefly from Java, the Philippine Islands and Ceylon. Kapok, like milkweed floss, is a seed fiber and is produced on the seeds within the large pods of the kapok, or silk cotton tree. This is a large, widespreading tree (*Ceiba pentandra* Gaert.) with enormous buttressed roots, native to the American tropics but now extensively planted in the tropics of both hemispheres. When the East Indian supply of kapok ceased there arose a

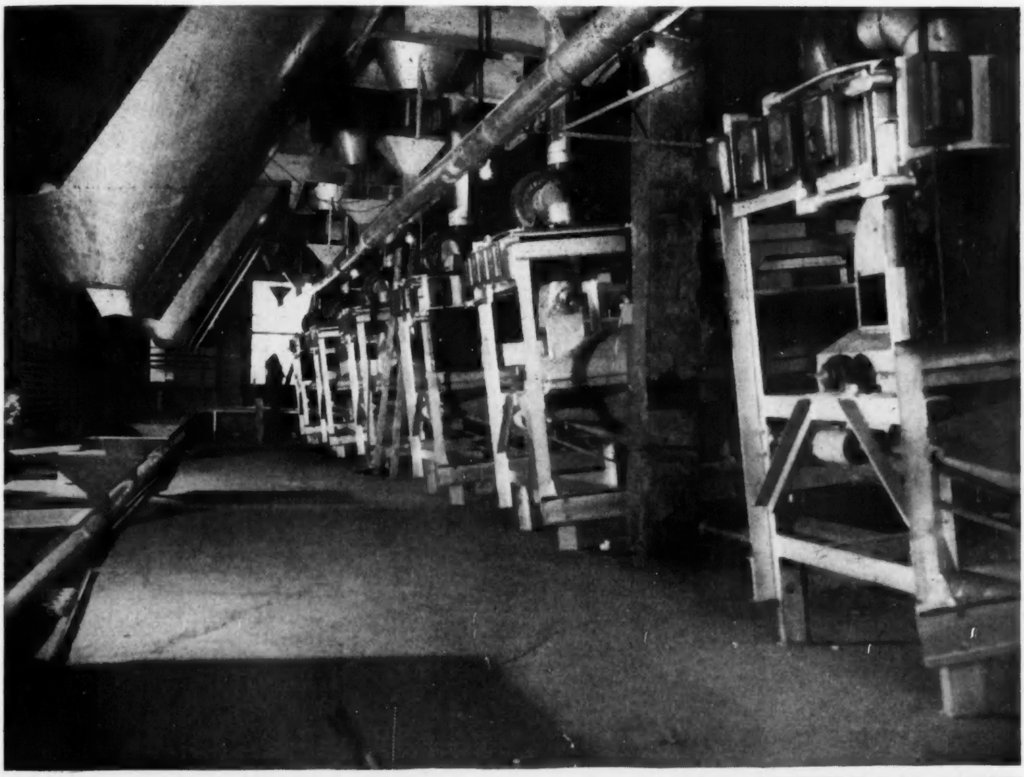

Fig. 2 (*Upper*). The "milkweed gin" which solved the problem of mechanically separating floss from seeds and thus tremendously accelerated the processing of these two plant products.

Fig. 3 (*Lower*). The baler which packed the floss into bales averaging 200 pounds in weight.

need for substitutes, as was true of so many other items of international trade, and the possibility of using milkweed floss in its place became apparent.

Inspired by this need, the author and his co-workers continued their efforts begun in 1938 to develop a satisfactory process for achieving the above mentioned aims. The result was a "milkweed gin" to accomplish them. In 1941 the author submitted to officials of the U. S. Navy a memorandum regarding the value of milkweed floss for life preservers and other life-saving equipment, and the next year he was invited to present his testimony before the Agricultural Committee of Congress. Tests conducted by the Navy proved that the floss is equal in performance for life-saving equipment to kapok imported from Java, and in 1942 the Federal Government appropriated over $200,000 to build a processing plant. The fund was administered by the Defense Plant Corporation, and the processing plant, the first of its kind in the world, was constructed in 1943 under the supervision of the author and Mr. L. J. Lyon, President and Vice-President, respectively, of the newly established Milkweed Floss Corporation of America. The plant was located in Petoskey, Michigan, in a region where the greatest concentration of wild milkweed in the United States is to be found. To furnish the plant with raw material, the Commodity Credit Corporation, as an agency of the Government, collected milkweed pods in 26 States with the cooperation of farm organizations, youth clubs, school children and other organized assistance. Over 2,500,000 bags were collected in the years of 1944–45, representing 25,000 000 pounds in green weight, or 10,000,000 pounds in dry weight. To transport this huge quantity of pods, 700 freight cars were used. About 2,000,000 pounds of floss were processed in the Petoskey plant in one single year, the floss representing about 20% of the gross weight of the pods, the seeds 36%, the podshells 44%. The floss was delivered to the armed forces during the war, to be used principally for the manufacture of life-preservers.

The pods were collected in wide-mesh onion bags, since they had to be air-dried in order to lose 60% of their water content before it was safe to stack them for transportation to the Petoskey plant. A huge specially built dryer, capable of removing excess moisture from a thousand bags of pods per hour, was installed in the Petoskey plant. Pods, after travelling on a conveyor through this dryer, were dumped on a second conveyor which brought them up to the second floor of the building where the contents of the bags were emptied into milkweed gins located on the first floor. The opening of the bags represented the only manual operation; the entire separation process was 100% mechanized. The milkweed gins and the attached air-separating units separated the pod content, allowing the floss to be carried by air to the huge collecting chambers; the seeds and pod shells were deposited on other conveyors which brought them to a separate collecting room. This air-separating system was operated so effectively that floss from pods not entirely ripe, or damaged by mold, was rejected. This prevented contamination of good floss by imperfect material, which was very important, because if floss gathered in the collection room was contaminated with mold, then baled, the outer layers of the bales would act as insulators and help spread the mold throughout the bales. Bales of floss imported from South America and other countries where hand-separation was used, sometimes contained large amounts of yellowish moldy material. The milkweed gin could also handle pods that had been only air-dried; but machine-drying, in addition to air-drying, made the gin

more efficient. In addition to assuring greater uniformity in drying than might otherwise have been achieved, the drying and processing method developed at Petoskey eliminated handling of the fibers by hand and thus provided a degree of sanitation that was of importance in certain lines of use. And, finally, it made possible the handling of billions of fibers in a fraction of the time necessary in hand operation.

Fig. 4. Ten-pound bags of air-dried milkweed pods in storage before processing at the Petoskey plant.

Utilization of the Floss

Milkweed floss is the lightest known material. It is one-sixth as heavy as wool, and lighter than down or kapok. Besides being a perfect insulator, it provides buoyancy. Therefore, suits made with this material quilted into the lining serve three purposes: they are lightweight, warm and buoyant, and, in addition, the lining is vermin and bacteria-resistant. The BTU of the floss is less than 0.24, and one pound, ten ounces of the material will keep a 150-pound man floating in water more than 48 hours. It was because of these qualities that the floss was utilized by the naval forces of the United States in recent years. However, milkweed floss could not be used in clothing as an insulating material unless special machinery could be developed to distribute the floss in absolutely equal thickness between textile sheets, and then by quilting, to prevent the shifting of the floss. In the post-war period such equipment has been developed, and it is now possible, therefore, to utilize the floss as an excellent insulating material for clothing, especially for regions having very low temperatures. Recent tests conducted on a large scale established the fact that milkweed floss is an insulating material of outstanding merit. Quilts of it became of value not only for insulation against cold, but also for sound-proofing, a usage that was justified by a Harvard University report (1) in which materials tested were found best in the following order: fiberglass A, kapok, milkweed floss, fiberglass B, kapok felt, fiberglass C, acoustical stonefelt, kumsel, fiberglass D. The least effective materials tested were fiberglass navy wool, foam rubber and hair felt.

In addition, the resiliency and compressibility of milkweed floss produced

by mechanized methods of separation have been found to be greater than in any type of kapok (34), and this feature created a great interest in the furniture industry for the floss as filling material. Other possible outlets, if commercial production of the floss is resumed, would include insulation for roofs and refrigerators. And, finally, the sanitary handling assured by mechanization renders the material suitable for use without further processing in bedding, children's toys and surgical dressing.

Milkweed as an Industrial Source of Fiber

The vascular tissue of milkweed stems, as is true of all dicotyledonous plants, forms a continuous ring without distinct bundles. This applies also, of course, to flax, hemp and jute, the world's foremost stem-fiber plants. In the center of older stems is an empty space which is originally filled with parenchyma cells, constituting the pith and occupying about 25% of the cross-sectional area of the stem. The pith gradually disintegrates as the stem matures, but a few fragments of it cling to the surrounding woody ring in mature stems. The woody ring is made up of vessels, fibers and parenchyma tissue; the fibers are approximately 0.5 mm. long and occupy at least 50% of the fully ripened stem. Outside the woody ring, or xylem, is a very narrow cambium layer, surrounded by the phloem tissue which consists of sieve tubes, bast fibers, latex tubes and conductive parenchyma. This bark-like material outside the cambium occupies 10% to 15% of the stem cross-sectional area, and it is the fibers within it that were used by the American Indians.

The author has never considered it desirable to use these stalk fibers for textile purposes, as was done by the Indians, for many other plant fibers are much superior. For the same reason utilization of the stalks for insulation purposes, compressed board, paper and other products, although possible, also does not appear to be the most desirable application. What is necessary for economically successful utilization of milkweed stalks is the production of additional synthetic products. Such additional products from the stalks are offered by the fact that the stalks can be split into two fractions—one, containing the bast fibers, representing 10% of the stalk, and the other the lignin fiber, representing 90%. The bast fibers having almost as high an alpha cellulose content as cotton linters, are suitable for making synthetic fibers, such as rayon, while the lignin fibers could be used for making lignin plastics.

The retting process, utilized by industry up to now for separation of hemp bast fiber from the woody or lignin fiber, naturally was injurious to the cellulose in the bast fiber of the hemp stalk, and damaging to the woody fiber. To avoid this, the author and his associates developed and patented a mechanized method of separation wherein the raw material is not exposed to the retting process, and, therefore, the valuable constituents of the milkweed stalk (cellulose and lignin) are not damaged and may be used with advantage for the production of synthetic fibers, such as rayon, or for plastics.

Mankind, in years to come, will depend more and more on raw materials produced as annual crops, and not on crops, such as trees, produced over a period of years. The valuable milkweed stalk, separated by inexpensive mechanized processes into cellulose fibers and lignin fibers, will unquestionably become a raw material of great value.

Milkweed as a Source of Oil, High Protein Meal and Wax

In 1938 the Milkweed Products Development Corporation established a research fellowship at Iowa State College.

Ames, Iowa, to promote extensive studies of oil, wax and other by-products derived from milkweed. The results confirmed the data of other investigators (19, 25, 38, 43) regarding the chemical properties of these by-products, and also established beyond doubt that mechanical extraction of oil by expulsion methods is not economically sound for commercial production, due to specific physical properties of milkweed seeds. Solvent extraction is the most suitable method, and most solvents used for soybean oil gave excellent results. The yield of oil by hexane extraction was 21.4%. A comparison of the iodine numbers of milkweed seed oil (122.6) and other oils indicate that it is a semi-drying oil, similar to soybean. Milkweed seed oil can be completely deodorized to produce an edible oil (41), and when properly refined will be satisfactory for the manufacture of alkyds.

In an article (24) which also gives data on the physical and chemical characteristics of the oil, on the analytical constants of alkali refined oil and on 52-R-13 long oil alkyds, we read:

"While milkweed seed oil does not possess sufficient unsaturation to be rapid drying by itself, the polymeric growth made possible in alkyd resin formation without the loss of unsaturation as occurs in conventional oleo resinous varnish formation, should greatly increase the drying capacity and film hardness. Moreover, the apparent lack of linolenic acid in the oil should make it ideally suitable in alkyds, for high temperature baking enamels, where color retention and flexibility are of paramount importance. The film from milk-

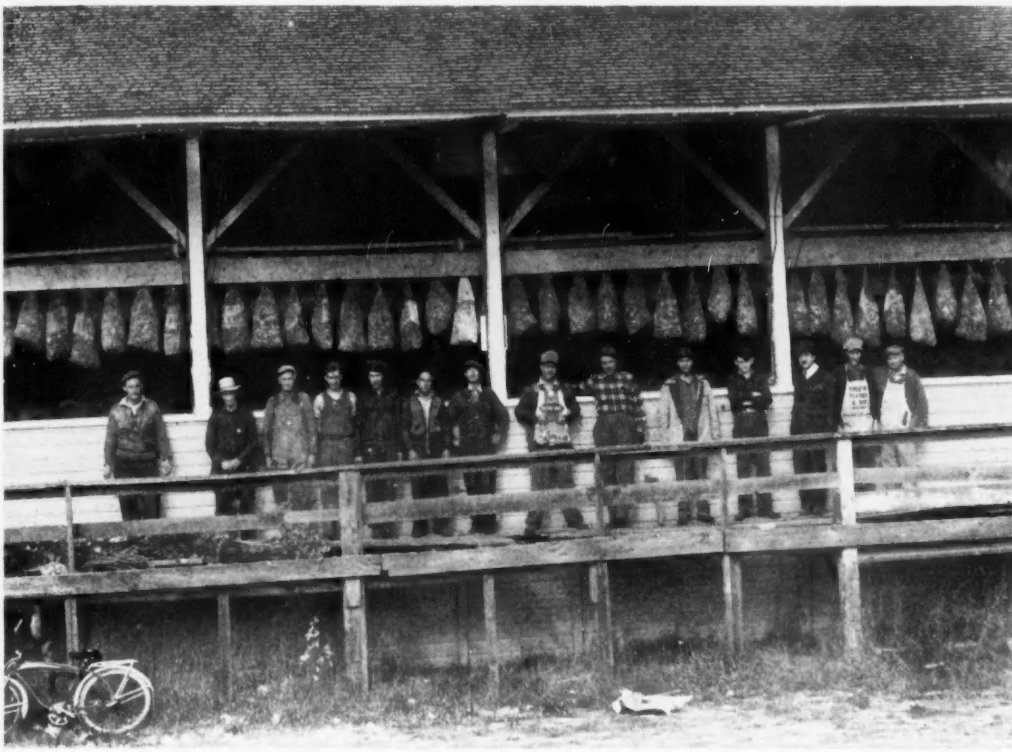

Fig. 5. Milkweed pods air-drying in onion bags.

weed seed oil alkyd showed remarkable resistance to discoloration, and was definitely superior to that of the soybean oil alkyd. . . . Our results indicate that milkweed seed oil is a valuable oil for use in the preparation of alkyd resins".

Since the seeds from which the oil is extracted are high in protein (40%), similar to soybean meal, they can be made into a plastic similar to that produced from soybean meal. The pod-shells contain a mixture of wax and gums, about 10% by dry weight, and a method of separation has been worked out. "The wax is similar in its chemical properties to Caranauba wax, and has a high melting point" (41).

During World War II, over 2,000,000 pounds of seed were produced, and all were readily absorbed by the private oil industries. The production and utilization of wax and meal was only on a small pilot plant basis; however, basic research shows good potential possibilities for these products.

Production of Milkweed as a Crop

From the agricultural standpoint a number of factors must be taken into consideration before any decision can be reached as to where and how milkweed plants should be cultivated. Numerous investigations have been conducted in this direction and reported in the literature of three countries—United States, Canada, Russia—the findings of which, together with personal observations of the author, are summarized in the following paragraphs. But first let us give some consideration to what has been done in the United States and other countries to investigate and to establish the basic requirements for the cultivation of milkweed.

History. Numerous attempts have been made in the past to cultivate milkweed, and 150 years ago there was controversy between advocates of the plants and scientists who regarded milkweed as useless. Under date of 1810, for instance, we read about the cultivation of milkweed in France (translated) (36):

"I published in 1808 certain observations on the subject of the Syrian Asclepiad. This little work was received with two opposite reactions. The true friends of agriculture, and of public and private economy, appeared to think well of it, and I received many flattering compliments, while those men who never cultivated the soil except in their dreams —undertaking, nevertheless, to be dictators in the field of agriculture, although they never acquainted themselves with it, and over which they pretend to reign as despots, unfurling above their heads the banner of exclusive ambition upon which is written in gigantic letters their favorite inscription—"None may have hopes but ourselves and our friends"— irritated that a mere cultivator dared speak of culture without having humbly solicited them and obtained their permission—they have cried , "Scandal, Ignorance, Charlatanism".

Sonnini states further (36) about the cultivation of milkweed in Germany: "In Silesia, the method of propagation is as follows: Seeding in early spring in a loose and somewhat sandy soil; seeds placed in grooves; germination in 8 or, at the most, 14 days. Young plants need some care; at the approach of winter, young plants are covered lightly with soil which is removed carefully in the spring. The second year the plants reach a height of 2 to 2½ feet, but the roots are still too delicate to transplant them successfully, and at the approach of winter they are protected against cold the same way as the first winter. In the following spring, *i.e.*, the third year, they can be transplanted. This is done best in April. Plants spaced 2 feet apart, giving each plant 4 square feet of area. A loose soil worked the previous autumn is chosen. Roots never placed deeper than 4–5 inches. If precautions

indicated are not followed, the plants will be tender and die in a short time. If done properly, plants will throw up sprouts and set fruit. However, the yields will not be very considerable in the third year. On an area of 18,000 square feet, containing 4,500 plants, 90,-000 pods obtained".

Fig. 6. Two young milkweed plants on a common root, illustrating the usual vegetative method of propagation as it occurs naturally.

Kuzmenko (23) gives the following summary and information about milkweed in Russia: "Due to the fact that cultivation and utilization of the Asclepias plant was successful in France and Germany, experiments of cultivation and utilization of this plant can be traced in Russia to the 18th century. . . In 1857, the government gave a license for production and commercial utilization of the Asclepias plant, to citizens Piroschkoff and Hartman (Kiev, Ukraine)".

In the United States a great deal of research has been undertaken since the turn of this century (3, 4, 5, 10, 11, 15, 17, 18). Especially interesting are numerous investigations conducted for many years at the Iowa Agricultural Experimental Station (10, 11, 19). In the annual report (1929–1932) (19), the summary is given as follows:

"The Milkweed has been grown under cultivation during the past three years. Problems such as propagation, yield and utilization of the various plant parts, have received attention. Yield studies, based upon the experimental plot, indi-

cate a production of 12.5 bushels of seeds, 100 pounds of floss and 1800 pounds of air-dry stem tissue per acre. This yield is low, due to overcrowding of the plants within the row, and represents approximately one-fourth of a possible maximum theoretical yield".

Moisture. Milkweed plants like moisture, the requirements for which are fairly heavy. Excessive moisture, however, appears to be definitely harmful, and yields are high either on moist soil with a water table not closer to the surface of the soil than one and a half meters, or in regions with not less than 20 inches of precipitation per year. This high moisture requirement is reflected in high transpiration; hence, as the air humidity decreases, the soil moisture of the site needs to be more abundant for sustained good growth. Regions of low air humidity are not unfavorable if the soil moisture is ample and the soil well aerated. Warm, dry soil, resulting from good exposure and drainage, is definitely advantageous. Water-logged soils, on the other hand, cause rotting of the roots. The sub-soil must, therefore, be such as to allow proper drainage, especially during periods of excessive rainfall; for this reason sand and gravel are the ideal subsoils. Fully grown plants withstand drought well, but young plants may easily be burned out by prolonged spells of dry weather.

Soil. *Asclepias syriaca* will thrive on any kind of soil, but it should be planted on poor soil because on rich sites it produces up to seven feet of lush vegetative growth with many stems and branches and an abundance of flowers, but sets few fruits. On light sandy soil it has shorter stems and fewer blossoms, but more fruits. Moist soil with a structure that assures adequate aeration is more favorable than dry soil, whether the soil be sand, sandy loam or clay loam. Loam produces the best growth, muck is very good, sand is good and clay is not so good as sand. The acidity should range from slightly acid to medium acid, or pH 6.6 to 5.7.

Exposure. Milkweed grows best in 30% to full sunlight, and thrives on sites unprotected from direct glare, even in dry warm climate if it has plenty of available soil moisture. In Michigan milkweed was not found in wooded areas, but high quality plants were abundant at the edge of those areas where the soil was richer in organic matter because of decaying roots, leaves and other vegetable matter. A longer growing season in the southern part of the range of *A. syriaca* helps, to some extent, to offset unfavorable site conditions. In the North, where less than 100 days are available for food storage during the growing season, the effects of poor site conditions will be more severe than in the South.

Nutrients and Competition. The absence of certain minerals, for example, boron, from the soil prevents the occurrence of milkweed in some areas. To supplement the natural supply of nutrients, a complete fertilizer is recommended. Clean-cultivated plots show the greatest response to nitrates. If ground-cover treatment is applied, fertilization is often dependent upon the ground-cover vegetation used. Hairy vetch plots, for example, show the greatest response to phosphate and potash. Climson clover, burr clover and blue lupine plots did not display any marked response to either phosphate, potash or nitrate. In experimental plantings all plots in winter-ground covers have been slow to bloom and to put forth fruit when compared with clean-cultivated plots.

Competition must also be taken into consideration when milkweed is cultivated. During the first and second years the young plants can not compete readily with other weeds. Weeding, therefore, is absolutely necessary dur-

ing that period. When the milkweed plants are well established, other weeds can not successfully compete with them. Experiments at the Iowa Agricultural Experiment Station, Ames, Iowa, and at the U. S. Department of Agriculture at Beltsville, Maryland, have established that it is difficult for milkweed to compete with blue grass the first two years. Canada bluegrass (*Poa compressa*), however, is not so vigorous a competitor as is Kentucky blue grass (*P. pratensis*), since it forms a thinner stand than does the latter.

Propagation. Milkweed is most effectively propagated by means of seed which should be sown either very late in the fall or very early in the spring. Fall sowing should be just before freezing weather so that gemination will not occur until spring. Spring sowing should be done as soon as the soil can be worked in order to take advantage of early rains. Seeding should be preceded by germination tests, rating the vigor on such factors as root length or number of lateral roots produced in a given period of time. Most milkweed seed collected from wild plants germinates very unevenly and slowly. Consequently it is most desirable that seed to be sown in the spring receive preliminary treatment in order to speed up germination or to obtain a greater percentage of germination. On the basis of our experiments the following treatment is recommended:

The seed should be soaked in water approximately four hours, then spread out in layers two to three inches thick where the temperature can be kept at 32 to 40 degrees F. The seed must not be permitted to heat during this treatment and should be kept at this low temperature 20 to 30 days; a longer period will give somewhat better results, but even a shorter period will be beneficial. During this time the seed should be stirred occasionally and kept fairly moist. About a week before the seed is to be sown it should be permitted to dry sufficiently so that it will run through a drill or planter. It must not, however, be allowed to become absolutely dry.

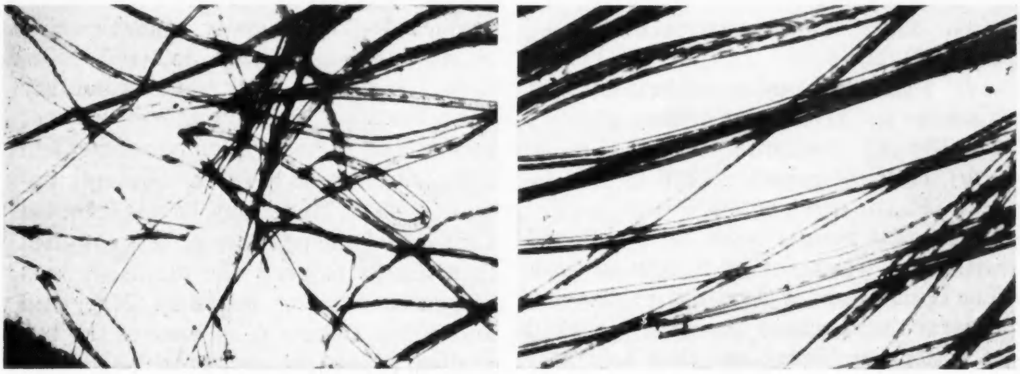

Fig. 7. Photomicrographs of kapok fiber (left), imported from Java, and of milkweed floss (right), collected and processed in America. Because of great transportation costs from Java (12,000 miles), kapok sent to America must first be compressed to weigh 14 pounds per cubic foot, and the high pressure used in the operation results in broken fibers, as shown. Milkweed floss, produced and utilized in America, need not be baled to greater density than five pounds per cubic foot, with consequent elimination of breakage, as shown.

Other methods suitable for improving the germination of milkweed seed previous to planting at half-inch depth are:

a) Scarification by abrasion in five degrees—very heavy, heavy, medium, light, very light.

b) Scarification by sulphuric acid

solutions of 5%, 10% or 20% strength for 10, 20 or 40 minutes, then washed.

c) Shaking the seeds vigorously at least 20 minutes in a Mason jar so that they strike the side of the jar with considerable force. A Peerless Mixer can be used for this treatment on a large scale, one revolution every two seconds. This treatment, like scarification, ruptures the inner seed membrane and permits the radical to emerge through it.

d) Freezing of moist seed for 48 hours at 20 to 30 degrees F.

e) Storage at 41 degrees F. for 30, 60 or 90 days.

f) Exposure to infra-red heat one foot distance for five, ten or twenty seconds, one, five or ten minutes.

g) Hot water bath at 100 to 120 degrees F. for eight hours.

The best results have been obtained with cold treatment of moistened seed. The Department of Agriculture, Canada, reports that seeds of *A. syriaca*, soaked in water four hours and then held at 1 degree C. for 25 days, gave 87% germination, and that seeds of *A. incarnata* under the same treatment gave 91% germination. Germination of untreated seed of the two species was 10% and 15%, respectively. In this particular experiment the seed was sown one-quarter inch deep in flats in the greenhouse.

Milkweed is self-propagating also by its rhizomes and is capable of producing suckers two feet from the parent plants. Such propagation is satisfactory for repeatedly raising crops provided the new shoots are confined to rows by cultivation of the soil between them. Artificial vegetative propagation, on the other hand, is not satisfactory because of the well defined rest period needed by the roots. Whether propagation is by seeding or by sprouts from the rhizomes, cultivation between the rows is desirable, and the rows should be maintained about two feet apart.

Other Considerations. Agroecological studies must be taken into consideration in appraising the results obtained so far in cultivating *A. syriaca* and in pursuing such cultivation in the future. Its wide natural range points almost certainly to the existence of ecotypes, and some of these may be very important in developing this species as a crop. In Kansas alone, for instance, there are over 60 species of Asclepiadaceae, and that State, therefore, should be very fertile in yielding various strains. This applies also to the closely related species, *A. Kansana* and *A. speciosa*.

In addition to the greater suitability of particular ecotypes, there are, of course, the factors of temperature, soil composition and bacterial content, humidity, *etc.* These may have accounted for some of the negative results obtained in attempts to grow the plants in such separated areas as Alabama, Maryland and North Dakota from some of the two million pounds of seed obtained during the war in the processing of the floss.

Economics of Production

According to the author's personal observations (3–5), which are in accord with those of others who have given study to the matter (10, 11, 19), an acre of land should theoretically produce one milkweed plant for each square foot, or a total of 43 560 plants. On the presumption that the dry weight of each stalk would be about one-eighth of a pound and that the stalks consist of 10% bast fiber and 90% woody fiber, an acre of plants would yield 5,445 pounds of dry stalks which would break down to 544 pounds of bast fiber and 4,901 pounds of woody material. The yield of pods per acre, on the basis of two pods per square foot of land and varying according to the size of the pods, would range from 1,089 to 1,742 pounds. Three pods per square foot would pro-

duce from 1,634 to 2,614 pounds, according to size.

From 100 pounds of green pods there can be produced 12.5 pounds of oven-dry floss, 23.4 pounds of oven-dry seeds, and 18.8 pounds of oven-dry pod shells. On the basis of two pods per square foot, each acre would yield 136 to 237 pounds of floss per acre; three pods would give 204 to 326 pounds; and the average would be 225 pounds of floss, 450 pounds of seed, and 335 pounds of pod shells.

These three products would find a receptive market in various industries, and the revenue to be realized from them is estimated thus:

225	pounds of floss @ $0.43, the average price in 1948 and 1949	$ 96.75
450	pounds of seed @ $0.05, the average price in 1948 and 1949	22.50
544	pounds of bast fiber, containing 90% cellulose for producing synthetic fibers, @ $0.04, the price of comparative raw materials	21.76
5,236	pounds of woody fiber (4,901 from the stalks, 335 from the pod shells) @ $9.00 per ton, the average price of similar material	23.40
Total estimated revenue per acre		$164.41

The above total represents the value of raw material obtainable from an average acre and allows ample margin for processing on the part of industry with a profitable return to the farmer when compared with the average yield of other crops, especially on submarginal lands ideally suited to milkweed but not favorable for such other crops.

Summary

The venture into industrial harvesting, processing and utilization of milkweed during World War II established the following facts:

a) That the principal products of industrial value to be obtained from milkweed plants are floss from the seeds borne within the seedpods, and bast fiber from the stalks to serve as a source of cellulose.

b) That by efficient separation of floss from seeds and podshells, the next most important product, the seeds themselves, which are a potential source of oil, can be obtained without significantly increased cost.

c) That wax, to the extent of 5% by weight, can be extracted from the podshells as a third by-product in obtaining the principal product, floss.

d) That, since the main products, floss and fiber, are bulky, the plants must be produced as an agricultural crop and not collected from wild-growing material.

e) That these main products can be obtained by mechanized separation, the milkweed gin doing the work of 1,500 men at hand labor.

f) That there are established markets for the main products—floss, fiber, seed—once their value in competition with similar products is accepted.

g) That if mechanization can be extended to planting, cultivating and harvesting the crop (pods and stalks must be collected separately), we shall have a completely mechanized industry that will contribute much toward meeting the world's ever increasing demands for plant products.

h) That the rubber obtainable from the latex, and considered by other investigators in the United States, Canada and Russia as the most important product to be obtained from milkweed, is only of minor value and can scarcely be seriously regarded as a potential source of industrial rubber.

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Utilization Abstracts

Bamboo Paper Pulp. Experiments are being conducted in Guatemala to supplement the citronella (*Cymbopogon Nardus*) bagasse now used in the paper mill at Los Cerritos with pulp obtained from an introduced species of bamboo, *Bambusa vulgaris*. This investigation was begun in March, 1949, with nursery plantings of this Madagascan species which, since its introduction of unknown date, has spread throughout most of the well-watered parts of the country from sea level to altitudes of around 5,000 feet. (*For. Agr. 13: 143. 1949*).

Bamboo Blowgun. In June, 1949, Dr. Bassett Maguire of the New York Botanical Garden returned after nearly eight months exploration for plants in Venezuela. Among the approximately 12,000 herbarium specimens which he brought back were specimens of the giant blowgun bamboo, *Arundinaria Schomburgkii*, only the lowermost internode of which, sometimes attaining a length of 20 feet, has been used by the Indians of a single remote jungle tribe, the Maquiritares, for their blowguns. Specimens of this giant grass had not been brought out of South America since the plant was discovered by Robert Schomburgk in 1839. It was located on Cerro Marahuaca and is known to the Indians as "curata", to the Venezuelans as "coriza".

"The Piarora Indians, north of the Maquiritares, are the only ones in this region known to make curare, the poison with which their neighbors tip their blowgun darts. Extensive trade goes on in these two products, both between these tribes and with others, all the way across the continent, until both blowguns and curare from the seldom-visited villages of these Venezuelan Indians are found in the markets of British Guiana and other east-coast countries." (*Jour. N. Y. Bot. Garden 50: 164. 1949*).

Manicoba[1] and Mangabeira[1] Rubbers

These two secondary rubbers are obtained from trees that occur naturally in moderate quantities in eastern South America and were used to some extent in meeting the rubber demands of World War II.

ROBERT W. SCHERY
Missouri Botanical Garden
and
Washington University

Introduction

During the recent war, with rubber imports from the Far East largely cut off and the Allied stockpile of crude rubber dipping to 45,000 tons in 1943, the United States Government expended considerable effort and money to procure rubber from any and all sources. Even after production of synthetic rubber had become well established, a critical need was felt for certain percentages of crude for compounding with the synthetic. Moderate amounts of plantation *Hevea* rubber were still obtainable from Ceylon, India and Africa, and in North America elaborate but largely fruitless programs were set up to obtain rubber from guayule (*Parthenium argentatum* Gray), a shrub of the American Southwest and northern Mexico, and from the Russian dandelion (*Taraxacum kok-saghyz* Rodin), seed of which had been obtained from Russia. In Haiti a sociological-rubber production program was initiated by the ill-fated Board of Economic Warfare in an attempt to obtain rubber on a large scale from two rubber-containing vines of Madagascar, *Cryptostegia grandiflora* R. Brown and *C. madagascariensis* Bojer. Throughout Central and South America every effort was made to obtain rubber from wild sources. Procurement of *Hevea* rubber from the Amazon valley, the original center of rubber production, was pressed, and the tapping of wild *Castilla* trees was again undertaken in Central America and western South America. Both *Castilla* and wild *Hevea* rubbers were well known, and the tremendous operations directed toward their procurement during the war need not be reviewed here. It might be mentioned, however, that *Hevea* has been introduced and cultivated in various parts of eastern Brazil, particularly in the State of Maranhão and in south coastal Baía near Ilhéus. A few minor plantings of several trees only are located in other eastern and northeastern States of Brazil. The plantings in Baía have been largely for cacao shade, except that since the war there has been some effort to establish rubber plantations there in their own right. The Maranhão plantings were made for the most part shortly after the turn of the century during the first rubber boom. In isolated marshy areas they have seeded naturally to such an extent as to maintain open stands. In Serra de Baturité, Ceará, there has been very sporadic cultivation of *Castilla*.

Little or nothing was known, however, of manicoba and mangabeira rubbers, the trees of which grow wild extensively over the eastern half of South America. The basic facts concerning these two sources, so painfully and sometimes ex-

[1] Pronounced man-i-só-ba and mang-a-beár-a.

FIG. 1. Map of eastern Brazil, showing the natural distribution of mangabeira and manicoba rubber trees. There is some mangabeira also in Para—on Maraja island in the mouth of the Amazon.

pensively gleaned during the war years by a corps of North American technicians operating in South America are assembled in this article. During the period 1943–1945 the writer personally visited at least once, every major producing area for manicoba and mangabeira in South America, and later correlated information on these areas as Senior Field Technician of the Non-Amazon Division, Rubber Development Corporation. Since the many reports are now "lost" in Government files, it may be useful to review and summarize the over-all picture of secondary rubber production in eastern South America.

MANICOBA RUBBER

Of the two types of rubber to be discussed here, manicoba rubber, from various species of *Manihot* (Euphorbiaceae), is of the better quality and ordinarily of the greater importance. Untreated manicoba crude rubber, naturally coagulated, has proven exceedingly enduring, lasting for years with inconsequential deterioration under ordinary warehouse conditions. Manicoba rubber appears somewhat more resinous than does *Hevea* rubber, but tests by Government laboratories on numerous samples from a variety of sources indicates inherent quality of the first order. Indeed, could manicoba be as economically produced as *Hevea,* by methods assuring a clean product, and in continuous large volume, there seems no doubt that it would be fully acceptable in rubber industries today using *Hevea* crude. Rubber content of manicoba latex is reported at 15–30%, with resins 3–15%. One species, *Manihot Glaziovii* Muell-Arg., has in the past been introduced from northeastern Brazil into East Africa for rubber production, and both *M. Glaziovii* and *M. dichotoma* Ule were at one time experimentally introduced into Hawaii and various parts of the Far East. The comparative smallness of the trees, their consequent lesser yields, and a horny outer bark inadaptable to precision tapping, rather than inferiority in rubber produced, were the factors mitigating against manicoba's success in competition with *Hevea.*

Manicoba Habitats

The various latex-yielding species of *Manihot* occur throughout the semi-arid caatinga region (3, 6) of northeastern Brazil. In most cases the smallish trees are found on intermediate slopes and elevations, particularly near the base or on the lower slopes of the small mountains (serras) or buttes common to most of northeastern Brazil. Apparently these hills afford wind protection and some subsoil moisture in a subxerophytic environment. Seldom do the lactiferous types occur along river valleys or on ridge or plateau tops. Stands are apt to be scattered into several nuclei within any one State, but may occur with fair frequency, up to 25 trees per hectare, within these nuclei. By and large they exhibit xerophytic adaptations, the most troublesome from the rubber production viewpoint of which is the horny impervious outer bark which hinders tapping. The climate of the region is marked by prominent rainy and dry seasons. During the latter, our late summer and autumn months, manicoba trees characteristically lose their foliage and often become so "dry" that tapping becomes unprofitable. During the few months of rains the manicobas leaf out and grow very rapidly. They are seldom tapped during the rainy season because of agricultural demands on labor and partly because of rain fouling the latex. Further pertinent mention of habitats will be made as the individual species are taken up.

Manicoba Species

The genus *Manihot* is very unsatisfactory from the taxonomic standpoint.

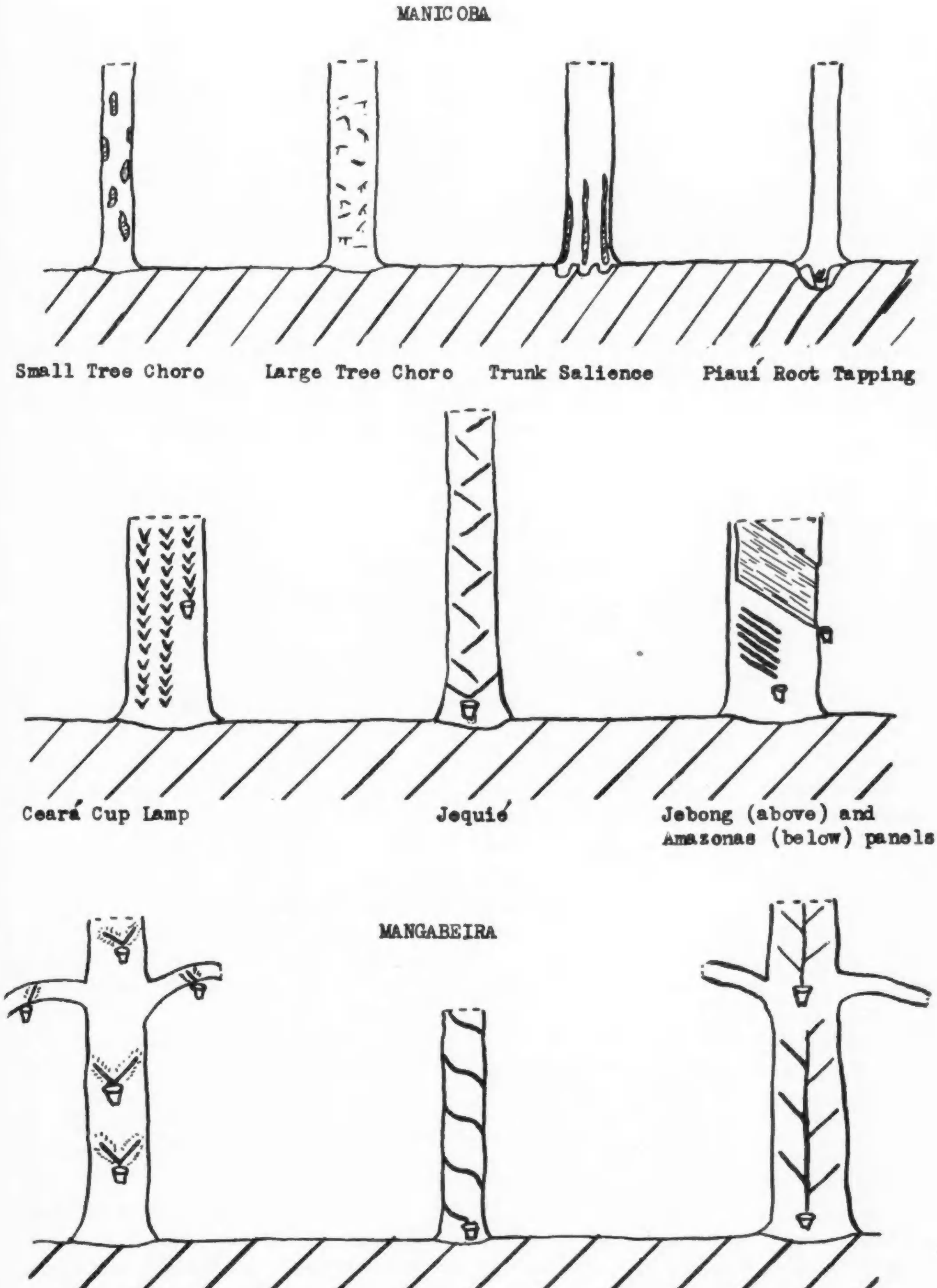


FIG. 2. Some practiced and possible tapping schemes with manicoba and mangabeira rubber trees.

There occur a great many variable forms, and intergradation between these is rampant. Tens if not hundreds of species occur wild (or naturalized? about habitations) throughout northeastern Brazil. For the State of Baía alone some 90 native species of *Manihot* were listed by one of the older German systematists, and although this number is undoubtedly excessive, even a conservative taxonomist would have little reticence in recognizing one-fifth to one-tenth this number. The majority of the species are not lactiferous, and scant attention has ever been given them. Even the lactiferous species, of some economic importance, have not been generally collected nor intensively studied. The famed manioc,[2] or cassava (*M. esculenta* Crantz) is known by hundreds of strains and forms, the relationships of which have never been adequately worked-out. There need be little wonder, then, that considerable confusion exists as to just which "species" is concerned in production and where ranges of overlapping species occur. Each species to be discussed in subsequent paragraphs must be regarded as a plexus of similar variants centering about a certain type or confined to a given region. All degrees of intergradation to other species can usually be found, and marked differences in yield among individual trees expected. As a rule, it is less confusing to refer to the manicobas by their common names, based mostly upon locality, gross similarity in appearance and tapping response, than to the latin name which cannot as yet be precisely delimiting.

Piauí Manicoba: *M. piauhyensis* Ule (northern part of range), *M. heptaphylla* Ule (southern part of range), and perhaps other minor species. *M. heptaphylla* is sometimes rather arbitrarily spoken of as "Sao Francisco manicoba", but in the trade is not distinguished from Piauí production, and is tapped and handled in the same fashion. Piauí manicobas are rather low, small to moderate, monoecious trees, with a smoothish birch-like bark, gnarled and spreading branches, and five to seven palmately arranged leaflets. *M. piauhyensis* usually has the leaflets more or less entire and with an ashy-green cast, while *M. heptaphylla* usually has sinuate lobations toward the tip of the leaflet and a purplish-green bloom. The trees possess a very marked taproot, the source of latex upon tapping. Piauí manicoba is the westernmost of all lactiferous manicobas. It occurs from northern and western Piauí east into southwest Ceará, and southward into western Pernambuco and Baía. Its heaviest concentration is in central and southern Piauí where it is a prominent element of the flora in the most vast of all manicoba nuclei. Within this large nucleus occur many intermittent stands. The area is one of sandy soils, hot sun, scrub forest and low, rounded hills, on the sides of which occur the trees. The sparse and disease-ridden population of the area is with few material comforts and poor and uncertain contact with the outside world. During the dry season even a mule is not to be had for transportation, because of lack of forage enroute. Feudal customs still exist, and the traditions of banditry, vengeance and independence of national mandate have not entirely disappeared.

Ceará Manicoba: *M. glaziovii* Muell-Arg. This is the largest of the manicobas in favorable environments, sometimes attaining diameters of 75 cm. d.b.h. The bark is rather thick, distinctly zoned into a soft lactiferous inner bark and horny outer bark. The leaves are palmately lobed with three to seven, though usually five, leaflets, having a grayish bloom. The trees attain their most luxuriant proportions in the comparatively moist Baturité and Maranguape serras

[2] Extensively discussed by the present author in Economic Botany 1: 20–25. 1946.

FIG. 3. *Manihot dichotoma.* A. Flowering branch. B. Bract. *M. piauhyensis.* C. Flowering branch. D. Flower cluster. E. Bract. F. Bracteole. G. Male flower. H. Stamens. (*From E. Ule*).

just south of Fortaleza, Ceará. Very different in dimension but presumably of the same species, are the small spindly trees of the rocky, dry bases of the serras near São Francisco and Sobral and the south slopes of the Serra de Uruburetama in western Ceará. This nucleus exhibits the opposite extreme in tree size and vigor from the condition found near Fortaleza. On the northern slope of the Serra de Uruburetama; in west-central, south and eastern Ceará; and in western and central Rio Grande do Norte, other serras offer habitat for trees of intermediate size and vigor. All Ceará manicoba is trunk-tapped by a variety of techniques. The area as a whole is arid, although perhaps not quite so inhospitable as is southern Piauí. The people, largely of mixed European-Indian blood with very little negro influence, are among the most industrious and tenacious of northern Brazil. As in Piauí, the entire economy is built about utilizing and storing the wet-season rains, and drought years wreak considerable hardship. Transportation is better than in Piauí, with a rail line and a dirt highway traversing the State of Ceará, and passable highways being found in Rio Grande do Norte.

Jequié Manicoba: *M. dichotoma* Ule. The third and last of the markedly distinctive lactiferous manicoba types is Jequié manicoba, found in a small concentrated nucleus about 75 miles long on the west slopes of the Serra de Maracás just west of Jequié, Baía. Jequié manicoba is a slender but rather tall tree with a very characteristic di- or trichotomous branching. With but little experience it is possible to spot *M. dichotoma* in the scrub forest, leafless during the dry season, by its distinctive outline. The outer bark is horny, but not as markedly so as with Ceará and Piauí manicobas. As with the former, trees are trunk-tapped. Leaves are three to five-lobed with a grayish cast. Here too climate is semiarid with distinct wet and dry seasons. Soils are generally sandy-clay, not so rocky as in Ceará and Piauí. The population of the area, usually bearing a proportion of negro blood, is sparse, for as in Piauí the carrying capacity of the land is low. A tradition of autonomy and rugged austerity has persisted but is giving away as the rail link with the coast permits greater intercourse and commerce.

Exploitation Progress and Possibilities

Piauí Type. Of the three manicoba types described, Piauí manicoba is the least systematically exploited and the most poorly evaluated. This is, of course, a direct reflection of the isolated and inaccessible localities in which it is found. Almost all tapping is carried on by illiterate unsupervised local inhabitants of the caatinga, if and when fancy pleases, and more or less conforming to demand and prices paid. Tappers may organize into gangs to spend weeks in the hills tapping, or more frequently may make daily trips from a permanent habitation. Wants are simple—a few shreds of clothing, a sack of farinha (manioc), occasional wild game and the humblest of shelter suffice. Pay or windfalls in excess of what is needed to supply these fundamentals permit idleness during days that might otherwise be worked. Ills are frequent and competent medical care non-existent. Transportation by truck is sometimes possible during favorable seasons. More commonly it is by mule over roads impassable to motor vehicles. Most frequently the worker simply trudges on foot. Scarcity of transport means poor selection and high prices for the few manufactured articles brought in. Supplies are frequently insufficient. It has never been possible to accurately evaluate the stands of manicoba over the entire area, but, estimating from selected samplings, it would seem that manicoba is encoun-

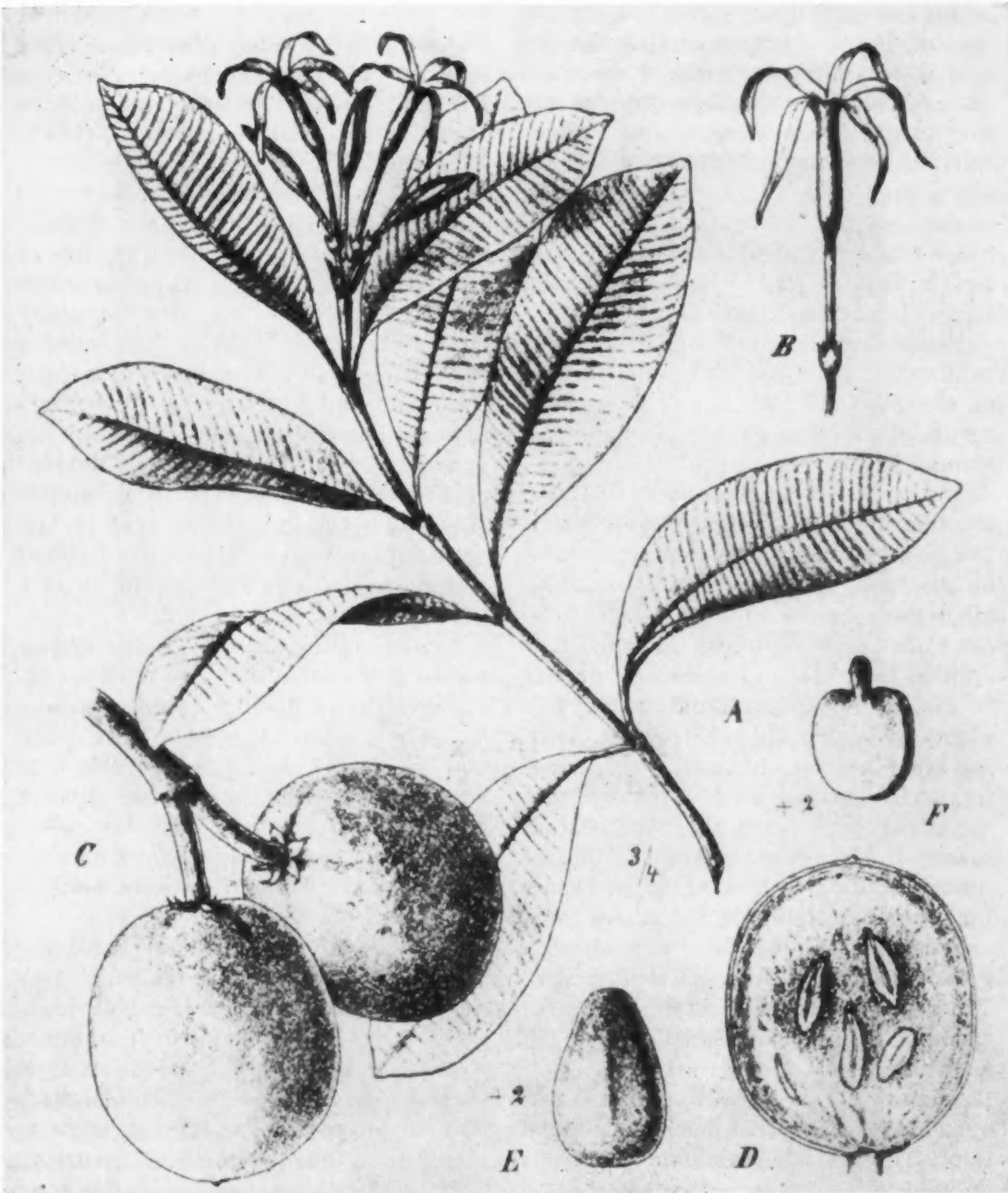


FIG. 4. *Hancornia speciosa.* A. Flowering branch. B. Flower. C. Fruit. D. Section of fruit. E. Seed. F. Young seedling. (*From O. Warburg*).

tered with moderate frequency in a fairly uniform series of clusters centering about the rather indistinct serras. It is not unreasonable to suppose that more than 50% of all usable wild trees were located and tapped during the war years, with the terrific pressure for rubber that existed then. Under most vigorous exploitation production from wild sources can never amount to more than a few hundred tons annually.

Ceará Type. Ceará manicoba is much

better known and more accessible than is that of Piauí. Transportation, supply and labor difficulties are not so great. In most localities perhaps 90% of the worthwhile trees were tapped under wartime pressure. Production of not more than 500 tons annually of all grades is possible from wild sources. Since this area has been treated by Cutler (2) in some detail, it is unnecessary to dwell further upon it here.

Jequié Type. Jequié manicoba, being confined to a comparatively small section of the State of Baía, can be the most accurately evaluated of all manicoba stands. Labor is unavoidably scarce, due to low carrying capacity of the land. Quoting from my Rubber Development Corporation Report 15 of March, 1944, on the Jequié area: "There is more of a labor shortage north of the Rio de Contas than in the southern section. The opinion most often expressed by dealers is 'give us a good price and we will find plenty of labor'. In other words, existing labor needs continuous 'organizing' into a functioning unit. It seems that the situation is much the same as that found in Maranhão, where the fact of 'underpopulation' is used as an excuse for a number of things, but where there are sufficient idle hands to accomplish a great deal, if set to a particular task. True, the municipality of Maracas, for example, is 'underpopulated', (as well it might be, for, banditry aside, . . . sertão country in its present state of development cannot support much of a population . . .), but the barraconista of Salgada finds no difficulty in getting 40 men to working rubber when it looks like profitable business. Nor do many fazenda owners and merchants report a shortage of workers. In most cases where there is a shortage of workers the reason is that the country cannot support more. Thus, before any idea of introducing laborers to such a zone is considered, what is going to happen to them must be thought-out. It is not merely a simple matter of transporting so many souls to a given locality. . . . Housing, food, water, contentment, jealousy of other inhabitants, animals, tools, clothing, communication, sufficient and enduring source of livelihood, *etc.* are each as significant to the worker as rubber. There are a great many facets that go to make up life or even existence anywhere, many of which are not foreseeable; and it is especially risky to tinker with the natural balance of life in a marginal area where a small error in calculation may have far-reaching and disastrous effects. Thus any importation of rubber labor to the Maracas area should be done cautiously, preferably under the guidance and at the responsibility of an established individual of the area, and in small quantity of a few workers at a time.

Labor working rubber in the Jequié region is the same that also must do agricultural work during the rainy season, *i.e.*, it is diverted to rubber work when nothing more pressing or desirable is at hand. Competing enterprises against rubber for labor, other than the necessary agricultural work, are work on Federal road and railroad projects, and extraction of ouricouri wax . . .".

Due to a thick impenetrable scrub undergrowth, necessitating cutting one's way to the manicoba tree, not all high-yielding trees were tapped even under wartime pressure. Along the Rio de Contas valley and south of this perhaps 90% of all trees were tapped, while to the north in the municipalities bordering Maracas perhaps 60–70% of the trees were exploited. Production of Jequié sheet from wild sources cannot exceed 300 tons annually.

Tapping Methods

Since each tapping scheme varies with the species in question and in accordance with local custom, few general statements can be made. With all lactiferous

plants, yields are best in the cool of early morning, so that tapping is best started at daybreak and not continued past noon. The difference in yield between

FIG. 5 (*Upper*). A gang of Piauí rubber tappers in manicoba country.
FIG. 6 (*Lower*). Small dealers holding dried Jequié sheets of rubber ready for export.

early and late tapping is not so marked with manicoba, however, as with mangabeira.

Piauí Manicoba. With Piauí manicoba, unlike all other types, the root alone is ordinarily tapped. Occasionally a few longitudinal cuts are also made on the lower trunk, but even illiterate tappers seem to realize that the small additional yield thereby gained is not compensatory because of permanent damage to the tree. The tapping routine, in brief, is as follows. A hole is dug in the sandy soil at the base of a selected tree.

This is ordinarily done with the tail end of the elongate tapping tool (lega) and exposes the prominent taproot. The hole is lined with a chalk-like dust (tabatinga) to prevent undue adherence of sand grains to the latex soon to fill the hole. A crescent-shaped gash one-third encircling the upper part of the taproot is made with the U-shaped head end of the lega. Flow of latex is immediate and lasts for several minutes. Under ideal conditions with high-yielding trees 100 cc. or more latex may accumulate in the dust-lined hole where it coagulates naturally within 12 to 48 hours. Typically the tree is visited again two days later, and the cake (chapa) of rubber removed or a second tapping made on top of it. In northwestern Baía tapping is daily for two weeks, then one set of trees let idle two weeks while another group of trees (estrada) is tapped, after which the first is again tapped daily. Ordinarily two, but sometimes several, tappings may be made to produce a final good-size chapa. Each tapping is made by renewing the cut of the bark on the lower edge of the original crescent. A slice of bark a few millimeters wide and completely to the wood is ordinarily removed with each tapping. Thus, as tapping proceeds, the hole must be dug progressively deeper, or a new hole must be dug on the opposite side. In the course of a tapping season, from the end of rains until the height of the dry season, a good part of the taproot of the manicoba is apt to become devoid of bark. It is no wonder, then, that mortality among trees is high, with few surviving many years of tapping.

Ceará Manicoba. Ceará manicoba is tapped in several manners, depending upon differing environmental conditions and partly upon custom. Cutler (2) has described and figured the different tapping systems of Ceará, so that only brief mention is necessary here. With the large trees of the Serras of Baturité and Maranguape near Fortaleza, V-shape notches up to 15 cm. across are typically hacked with a machete, and a tin latex cup inserted in the bark below the angle of the V. On large trees several cups may be placed, with yields of several cubic centimeters of latex to each cup. Subsequent cuts are made a centimeter or so below the previous one, until the series of tapping wounds runs to the base of the tree. Thereafter a new series is started in an adjacent bark area. Tapping is typically daily except for weekends, holidays or rainy days. Jebong tapping, as practiced on the *Hevea* plantations of the Far East, is possible but not practical because of the care that is needed. Amazonas panels (slanting parallel cuts with narrow strips of bark between) have been tried but have never been widely accepted.

Trees of drier localities, such as near Assaré and in eastern Ceará–western Rio Grande do Norte, may simply be hacked with a machete, and the exuding latex let drip over the bark. At two-week intervals the strings of coagulated latex so produced are hand picked from the bark to be sold as tear drop (choro) rubber, a low quality low-price type. In the drier parts of the Serra de Uruburetama of western Ceará and the Serra de Santàna of Rio Grande do Norte, where trees are extremely small and climate arid, entire sections of bark are hacked from the small trees. At about two-week intervals the choro rubber is picked from the edges of the wound or from drippings on the bark. With the small yields obtainable this system of bi-weekly visits is the only practical one over the rough terrain.

Certain moderate size trees of the Serra do Machado west of Canindé and elsewhere are treated somewhat as is Piauí manicoba. A tabatinga-lined hole is dug at the base of the tree, but instead of tapping the root, vertical saliences of the lower trunk are opened, resulting in

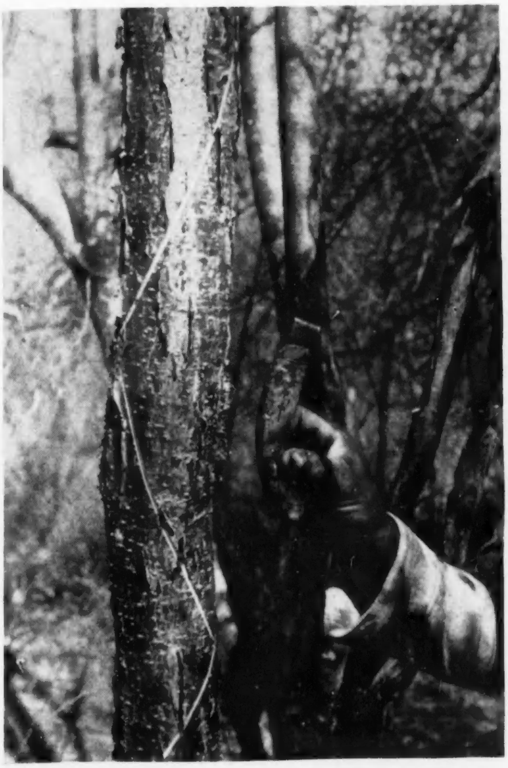


FIG. 7 (*Upper left*). Jequié tapping knife and Jequié manicoba tree at first tapping.

FIG. 8 (*Upper right*). Herring-bone tapping of a large mangabeira tree in northern Paraguay.

FIG. 9 (*Lower left*). A Jequié manicoba tapper and his son.

FIG. 10 (*Lower right*). A Jequié manicoba tree in the caatinga on the western slopes of Serra de Maracas, Baía.

sufficient flow to form a chapa plate. Tapping is at irregular intervals, and renewal cuts are made at the margins of the old wound.

Jequié Manicoba. The tapping system practiced in the Jequié area is rather unique for manicoba and greatly resembles a refined form of that used with chiclé (*Achras zapota,* chewing gum) in northern Central America. It is severe but perhaps the most feasible for the area where daily or even weekly tapping is impractical. Again I quote from my Report 15 of March, 1944: "The technique of tapping Jequié manicoba presents an interesting case of the powerful influence of custom and teaching on the habits of a region. Other than the fact that back before the first rubber boom Frank introduced the present system of tapping on a region where nothing was known of manicoba or rubber tapping, there is no apparent reason why this distinctive system, different than that used in every other manicoba district of Brasil, should have caught on in preference to others. There seems no logical reason why tappers should today insist on using a cylindrical 'canuto', thus having to slice by hand a cylindrical-shaped coagulum, when flat coagulating pans or any available vessel would serve equally well or better. Frank was a rubber pioneer in a field that was new: he inaugurated a system he thought good, both for Jequié and Hawaii. This system is undesirable from some standpoints, highly desirable from others. The system caught-on (there being no knowledge of others, hence no choice), has 'stuck' ever since. Father has taught son for three generations the details of the Frank tapping technique, and now even should change be desired, the biggest — (propaganda barrage) — would scarcely sway the system with roots so ingrained in the custom and economy of the region. We can well be thankful that Frank was an intelligent man, introducing a system that produces a product superior to that of any other manicoba region. And for the Jequié region, who can say (without years of experimentation) but that it is the best all-around system.

"The Jequié system of tapping is—shown—. The entire tree, from uppermost branches to base of trunk, is tapped by a series of zig-zag cuts by the tapper, who climbs the tree or may boost a boy up for tapping the higher parts. Usually these zig-zag cuts do not meet, but a small area of bark is left between them over which the latex runs, being caught below by the following cut or cuts. This, when practiced, is, of course, helpful to the tree in that the conducting system of the tapped bark is not entirely disrupted.

"If intelligently done, this tapping is practiced only on one half of the tree: a continuous panel of untapped bark will remain on the back side. Tappers have found that if tapping is done on all sides, the tree will die.

"At the base of the trunk a large V-cut is made (usually three-fourths around the tree), to act as a final channel for catching all latex dripping from above and for conducting the latex to the single latex cup located at the vertex of the V.

"The tapping cuts are made with a small knife locally made. This knife has a small curved handle just large enough to fit the palm of the hand, a sharp, very narrow V-shaped head somewhat like that of the Hyde modified Amazonas knife. The tapper, descending the tree from above, makes the zig-zag cuts with a series of quick sweeping thrusts. These cuts reach to the wood, certainly must be damaging to the tree (especially considering the large number made at one tapping: the bark of a tree, being gashed open from top to bottom, demands much of the tree for good healing).

"On trees previously tapped, especially deep cuts (often into the wood) must be made in order to insure flow down the channel of the new cut, rather than drip into old channels. On heavily tapped trees many extra cuts must often be made to conduct dripping latex into proper channels.

FIG. 11. Mangabeira trees on Boipeba Island, Baía.

"In cases where the descent of the tapper is not rapid enough to reach the base of the tree before the flow of latex from the upper branches, he may temporarily locate a latex cup high on the trunk to catch this latex. After continuing the tapping channels to the base of the tree, he withdraws this latex cup, emptying its contents into the one located at the base of the trunk. If further tapping is then still required on the higher parts of the trees to conduct latex properly to the base, the tapper covers the basal cup with a hat to avoid having cuttings of bark fall into it.

"Latex continues to flow from the tapping cuts for about five minutes, anytime after which the latex can be collected. In practice the tapper taps as many trees as he has latex cups (usually about 35), then returns in the reverse order to gather the latex (last tree tapped first visited on return). Sometimes he may send a boy to gather the latex".

Coagulation of Latex and Treatment of Coagulum

In all cases manicoba latex is let coagulate naturally without addition of any coagulant. Coagulation is normally rapid and seldom takes 24 hours. Quite probably oxidation and evaporation are more effective in causing coagulation than is acidification by fermentation, for thin layers of latex will coagulate within a few minutes before any microbial activity could be overly influential. After coagulation the coagulum is cleaned if necessary, then dried in the shade for a few days to several weeks before selling. Ultimate price received will depend largely upon cleanliness and degree of dryness. Frequently large chunks of coagulum are cut to facilitate drying. Top grades of manicoba crude permit no more than 18% moisture.

Piauí chapa. As has been described, this is rubber coagulated in the tabatinga-lined hole at the base of the tree. Any serum (supernatant liquid left by the coagulum) is absorbed by the tabatinga and soil, so that disagreeable fermentation odors are of less intensity than with cup-lump. If the hole is carefully lined with the chalky tabatinga dust, practically no sand adheres to the coagulum. The dust that does adhere and any chance grains of sand are washed off by severe brushing and scraping under water. The chapa is then dried and marketed. Irresponsible tappers often try to load the chapa with sand, for purchase is on a weight basis. This is commonly accomplished by kicking sand over the chapa between tappings. Buyers soon learn to watch for such tricks, and usually cut large or sample chapas before consummating purchase.

Ceará cup-lump. Where latex cups are used to collect latex, as in the Serra de Baturité, barring afternoon rain, the latex coagulates in the cup. Unless yield is very large subsequent tappings are let flow on top of earlier ones until Saturday when the cup-lump is removed for drying. Serum has no escape and typically ferments to create extremely foul odors. Cup-lump coagulum is clean, however, provided no bark or debris is introduced into the cup during tapping, and of very high quality. Little or no washing is necessary, but drying may be slow unless the cup lumps are sectioned.

Ceará choro. Choro is the dirtiest and tackiest of all manicoba rubber. It has been mentioned that coagulation occurs directly on the unprotected bark or at the edge of wounds. Fragments of bark unavoidably adhere to the rubber as the tears and scraps are torn loose. Moreover, these rubber scraps have remained exposed to the sun for many days, a condition conducive to tackiness. In normal times there is little market for choro, and even during the war great stress was laid on washing and creping this type. Such cleaning was accomplished in Brazil at market centers (Fortaleza and Natal) by passing the choro fragments between two differentially rotating rollers while a stream of water played over the mass to remove loose dirt. Large machines are needed, and the process is too expensive to be economical under ordinary circumstances.

Jequié sheet. Highest quality of all manicoba rubber is Jequié sheet. The preparation process can be outlined by continuing my Report 15 quote:

"The latex cups are then emptied into the 'canuto', a cylindrical, locally made vessel holding from 3–5 liters of latex. All latex is swept from the latex cup into the canuto with the flat of a finger. If the latex of some cups should be partially or wholly coagulated it is emptied into the canuto nevertheless (latex of some trees seems to coagulate more rapidly than that of others).

"The canuto of latex is left to coagulate naturally. Coagulation may occur in as little as a few hours, especially if latex is left in the sun, but 12 hours is considered more or less the average length of time needed. Smaller quantities of latex in open latex cups may coagulate within an hour's time. The coagulation point seems to be reached more or less abruptly after a certain period of organic reaction during which the latex expands and foams. The coagulum settles to the bottom of the canuto, and a colorless supernatant serum remains above. This serum, in the cases seen, amounted to roughly 15–20% of the original volume of latex. It is of no value and is poured off by the tapper.

"The coagulum is emptied from the canuto onto a board or mat where it is 'rotarily' sliced by hand. For this slicing any sharpened knife or machete serves. The sheet resulting from this treatment is still quite soft and wet. It is therefore rolled about a stick, being manipulated to press out excess serum. Afterwards the sheet may be passed through a cylinder, if such is available, to further express liquids. It is then hung in the shade to dry.

"At this stage the sheets are classed as 'borracha da semana' and are still wet enough to undergo up to 50% shrinkage before a thoroughly dry sheet is obtained. The tapper sells his rubber to the 'barraconista' or other dealer in the 'borracha da semana' condition. Occasionally this rubber may be lightly smoked.

"When this rubber reaches the warehouses of the dealers it is hung on racks for further drying, where it may remain for a number of weeks. In Maracás all rubber received is washed overnight in water to soften the resins and to wash off dirt, then cylindered on adequate machines and later racked for dry-

ing. The rubber when well dried is ready for shipment to Salvador''.

Handling and Marketing

Most manicoba rubber is bought in the interior by the barraconista system. This is particularly true of Piauí chapa. Small dealers in the remote villages or ranches, typically agents of larger exporters, advance supplies to tappers where necessary, to be paid-for in rubber. Rubber becomes currency, and so-many kilos of rubber are worth so-many kilos of food or other necessities. The barraconista, the local buyer or capitalist, sells supplies at as high a price as possible, and pays in produce as little as possible for rubber. These small dealers accumulate quantities of rubber sufficient for shipment, and in turn sell to

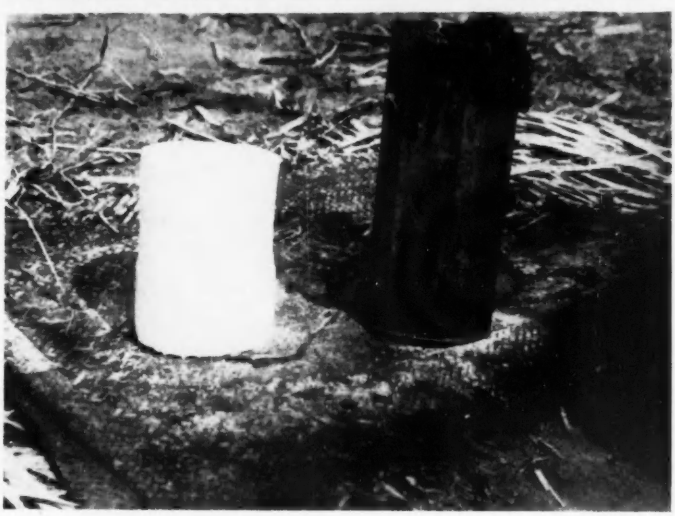


FIG. 12 (*Upper*). An interior taboleiro, typical of Minas Geraes and Baía, Brazil, where much mangabeira is found.

FIG. 13 (*Lower*). A canuto for collecting Jequié manicoba latex (right) and naturally coagulated coagulum (left) after removal from the canuto.

larger exporters. Usually they dry the rubber to attain a higher grade and cheaper shipping.

The rubber is then usually sent by mule train to larger interior cities where agents of larger exporters may further clean or dry it before shipping, usually by rail, to the large ports. Principal export ports are Fortaleza, Ceará and Salvador, Baía. The system of large series of middlemen profiting at the expense of the tapper did not sit well with some North American policy makers during the war. It was soon proven, however, that maximum production at reasonable cost could be obtained only by working within established channels. Each middleman was useful in forcing someone further down the scale to keep production going.

The Manicoba Stands

Mention has already been made of the tremendous variability within the four species of manicoba discussed. There is also variability in yield between individuals of the same species, and between these species and "manicoba brava", *i.e.*, wild manicoba, worthless for rubber. All degrees of intergradation in yield and morphological characteristics can be found between lactiferous and "brava" types. So similar are some non-lactiferous specimens to high-yielding adjacent trees that it is a common sight to see trees experimentally cut by hopeful would-be tappers. Trees so marked with a few experimental cuts are soon abandoned. In some cases after a few tappings giving unsatisfactory yields a tree will become productive enough to be worth future attention. This is due to the phenomenon of wound-response, so well known in *Hevea*. Yields from a newly tapped tree gradually increase to a plateau during the first several tappings. Illiterate manicoba tappers frequently are seen to "amansar" (tame) the wild trees by means of several preliminary woundings before engaging in serious tapping.

Unfortunately little has been done to

FIG. 14 (*Upper*). Tapping the root of Piauí manicoba.

FIG. 15 (*Lower*). Young Piauí manicoba tree in a cleared area.

select stock and improve yields as has been done with *Hevea*. During the first rubber boom many plantings of manicoba were made in Ceará, in northwest Baía and in the Jequié area. Several million manicoba trees are reported to have been planted in northeastern Brazil during the first decade of this century. Plantings were made also in East Africa and the Far East. But the bubble soon burst, and little remains today of the unattended plantings, usually away from the natural environments best suited to the species. Many plantings were cut for fuel or to clear the land again for agriculture. Thus there was no opportunity for constant selection and propagation from selected varieties. Most of the original plantings seem to have been made from unselected seed with no possibility of yield prediction. Plantings made from cuttings gave high mortality, but even with this kind of propagation no marked program of selection was followed. Even the meager plantings initiated during the recent war apparently utilized the cuttings not thoroughly selected for yield.

Heavy tapping during the war undoubtedly caused worsening of the wild stands. Quite naturally high-yielding trees received most frequent and heavy tapping, resulting in death to a large percentage. It is probable that in heavily exploited districts as much as one-third or one-half of the best yielding trees had been killed or were moribund by 1946. Not only were these trees themselves eliminated, but their presumed utility to transmit high-yielding characteristics to offspring was thus cut short. It would appear that only intelligent planting programs can assure significant manicoba production for the future.

MANGABEIRA RUBBER

Mangabeira rubber is obtained from several strains of a single species of *Hancornia, H. speciosa* Gomes, of the Apocynaceae. This species occurs in the wild only, scattered in almost all States of Brazil south and east of the Amazon valley and in northeastern Paraguay. In some locations it attains robust proportions, diameters up to 50 cm. d.b.h. and heights of 15 m. In others it is a spindly willow-like dwarf, usually compensating for its small stature by greater frequency. The bark is thick and soft, possessing a conspicuous cork-layer in old age. It is easily cut with even a dull tool. Latex vessels occur in the inner bark, and once severed, unlike those in manicoba, drain the latex in a sudden gushing flow for considerable distances to each side. Several weeks or months are required to regenerate new latex sufficient for a second tapping, and in dry years only a single tapping may be feasible. Mangabeira branches are typically gnarled and drooping. The simple, opposite, elliptic leaves have characteristic parallel secondary veins. The white flowers are perfect, small, fragrant, borne towards the tips of the finer branches. The fruit is a large greenish berry, becoming brownish or reddish when ripe. Mangabeira latex was in heavy demand during the war years, although this rubber is of inferior quality and less dependability than that of manicoba or *Hevea*. Resin content is usually 10–13% in comparison with the usual 4–5% for *Hevea*. The latex has also been locally used for waterproofing cloth, as a rubber cement, and reportedly as a tonic. The persimmon-like fruit is highly esteemed when ripe.

Mangabeira Habitats

Mangabeira appears to be restricted to poor, porous, sandy soils in localities of moderate to moderately low rainfall. Such areas are marginal grassy forests, sparse parklands or savannah, studded with a loose stand of trees, mostly mangabeira, cajú (*Anacardium*, the cashew)

and various representatives of the Dilleniaceae, Malpighiaceae and other families. Mangabeira predominates on flat-topped elevations, known as "taboleiros", having the characteristics just described. These taboleiros, or tablelands, occur intermittently in a narrow belt along the sea coast from Pará and Maranhão, through Piauí, Ceará, Rio Grande do Norte, Paraiba, Pernambuco, Alagôas, Sergipe and Baía to Espirito Santo. Paradoxically they are further found in the interior far from the coastal environment, but again midst similar ecological and soil conditions. Interior taboleiros are located in Maranhão, Piauí, southern Ceará, and extensively in western Baía, Goiaz, Minas Geraes and Mato Groso. Small stands are found to the south in northern São Paulo and northern Paraguay.

In most of these locations agriculture is impossible. Grazing of cattle on open range may be practiced in the more habitable portions. In the latter case an unfortunate concomitant is the annual dry-season burning-over of the land. Belief has it that such burning somehow improves the grass. It does cause tender new leaves to arise, perhaps more palatable to cattle than the coarse dry stalks, but humus is lost, the soil impoverished and arborescent vegetation set back. Only thick-barked woody species survive; mangabeira in such areas may be 25 years old and not more than five centimeters in diameter. Practically no passable roads exist over the loose sand, nor is there sufficient labor available to make and keep up roads. Living conditions are of the most primitive sort. Only the poorest of Indian and negro-blooded people occupy the area. Supplies are almost non-existent, and food and water must usually be hauled in by mule or by human carrier.

The tappers of mangabeira on the more isolated taboleiros lead a semi-nomadic life. Rude mud and stick huts are thrown up for nightly protection, while all members of the group or family scour nearby localities for mangabeira, hoping also to find sustenance—wild fruit, such as cajú, and occasional game. Once accessible trees have been tapped the group moves on to other locations, for at best mangabeira can be tapped only three or four times per season.

Tapping Techniques

Mangabeira must be tapped in the cool of the morning to give profitable yields. Flow is noticeably less after midday and towards the end of the dry season. The latex is white or pinkish, and the rubber produced becomes reddish on the exposed surfaces. Mangabeira tapping is so completely unsupervised and practiced by illiterate people antagonistic to innovation that techniques largely follow local custom with little regard for improvement. The more prominent generalized techniques can be mentioned here, but it must be remembered that local modifications or exceptions to these occur frequently within the ranges specified.

Some of the worst tapping occurs in the backward State of Maranhão, Brazil, and neighboring Piauí. There longitudinal gashes, or scrapings to thin the bark, followed by a series of incisions cause latex to exude and flow down the trunk. This latex may be gathered by a spoon and emptied into a gourd as it flows, or even let accumulate in a hole at the base of the tree. One such tapping makes the tree unfit for any future tapping and often kills it outright. Even roots are sometimes tapped there and in isolated localities along the Baía coast as well.

A more rational procedure is practiced in the coastal areas of Ceará-Baía, although even here local haphazard gashing is not uncommon. A V-channel is pared in the outer bark only, and a knife-edge cut made at the center of this

Fig. 16 (*Upper left*). Rolling Jequié coagulum to express water after it has been sliced to sheet thinness with a machete.

Fig. 17 (*Upper right*). A badly scared and therefore nearly worthless mangabeira tree of the west Piauí-Maranhão zone in Brazil.

Fig. 18 (*Lower*). Legas, or tapping tools, for Piauí manicoba root tapping.

channel to the wood. Several such V's may be made at intervals on the trunk and lower branches. The knife edge cut then severs the latex vessels, permitting sudden copious flow into a tin latex cup or molded leaf inserted in the bark just below the angle of the conduction channel. Very similar is the technique usually employed on interior taboleiros in western Baía, Minas Geraes, Goiaz, Mato Groso and southern Ceará. Specially designed knives with a U-shaped head on one end and a knife-edge on the other are employed. A conducting channel is made in the outer bark by the U-shaped head, followed by severance to the wood with the knife-edge. Unfortunately many careless tappers cut all the way to the wood with the U-head, causing wounds that are slow to heal. At times longitudinal connecting gashes are made between V-channels, so that one latex cup may serve two or more tapping locations.

In Paraguay and parts of Mato Groso and scatteringly elsewhere, a herringbone system of tapping is used on the large trees. An elongate but shallow vertical channel is made into which run several lateral channels from all parts of the tree. The channeling is done with a U-headed knife and is followed by knife-edge cuts all the way to the wood, made with any available blade. Two to four panels of this type are typically opened on the lower trunk, upper trunk and larger branches. The lateral channels are inclined about 45°. At the base of the vertical channel a tin can is inserted in the bark to catch the draining latex. The same vertical channels will serve for several tappings, merely by cutting new laterals. Interval between tappings is typically about six months. With this system as much as five liters of latex can be obtained at a single tapping from a large tree, but a more usual amount would be not more than one liter at the first tapping. With the small trees of the coastal taboleiros, 100 cc. of latex per tree would be an exceptional yield. In some coastal areas (Esplanada, Baía) it is necessary to make a continuous spiral cut from base to tip of the small trees in order to get enough latex to one-fourth fill a single latex cup. Such spiral tapping or a zig-zag modifi-

FIG. 19. A mangabeira tree near Ituveraba, Sao Paulo, with multiple tappings, as evidenced by the several latex-collecting cups on the trunk. (*Courtesy of Dr. H. C. Cutler*).

cation of it are the dominant tapping methods throughout Sergipe.

Latex Coagulation

Contrary to the simple natural coagulation of manicoba latex, coagulation of mangabeira latex offers many possible procedures, and many uncertainties. Intensive study was directed during the war years towards finding the most suitable coagulation procedure, but no conclusive results were obtained. For one thing, mangabeira latex from different

localities gives different quality coagulum with the same coagulant. For another, treatment of the coagulum after coagulation may have more influence than the means of coagulation. Certain graders seem to favor rubber coagulated by one means, while other graders favor another. All-in-all, the most efficient procedure for the undependable stubborn labor is to employ the least expensive and simplest materials. In some localities fine quality mangabeira results, no matter which coagulation technique is used. In others the rubber invariably turns tacky in short order. The various coagulation procedures consist of natural fermentation, boiling and use of alum, salt, acid, various unusual chemicals or smoking.

FIG. 20 (*Left*). Good V-tapping and cup collection of mangabeira latex near Axixá, Maranhão, Brazil.

FIG. 21 (*Right*). Typical tapping of manicoba (*Manihot Glaziovii*) south of Fortaleza, Ceará (Maranguape). The small machete in the cutter's hand was used to make the V-cut, and healed cuts from previous tappings are visible on the trunk. (*Photos courtesy of Dr. H. C. Cutler*).

Natural Coagulation. This procedure was intentionally practiced during the war only scatteringly, for mangabeira latex is notably slow to coagulate naturally, requiring days or even months to do so. In a few cases tins of latex have been "forgotten", or left in a truck many days in the sun to coagulate naturally. In all cases of natural coagulation which have come to the author's attention, the rubber so produced was of excellent quality.

Boiling. Boiling is most commonly practiced on the east coast of Brazil, and here and there in Minas Geraes and Goiaz. Latex, preferably strained and sometimes diluted, is boiled over an open fire with constant stirring. As pockets of uncoagulated latex form within the coagulum they are exploded by the stirrer. Within a few minutes a soft

thick coagulum forms, containing in excess of 50% water. Boiling may be accomplished in any kind of container, and in isolated taboleiros is usually in crude earthen pans. To form a higher grade product, such soft coagulum must be pressed free of excess water. In buying-centers water is expressed by passing the coagulum between cylinders similar to the wringer of a washing machine, while on the taboleiros this is commonly accomplished by stamping on it. Heat-coagulated latex was generally found more acceptable than other types by the Salvador grader during the war years.

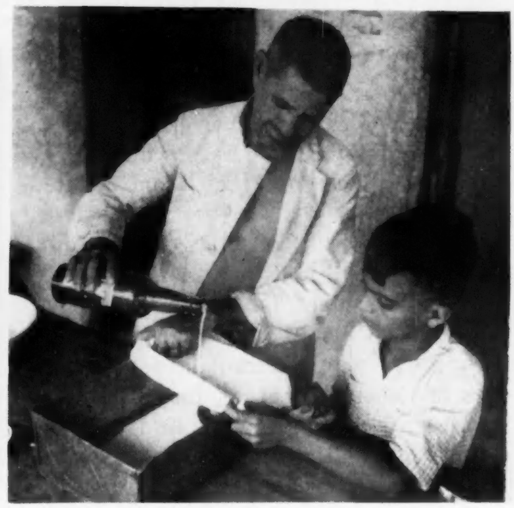
Alum. Alum, or alum plus salt, is one of the most frequently used means of coagulation of mangabeira latex. Coagulation is instantaneous, giving a good workable coagulum with the use of very little alum. Expellation of excess water is necessary as with boiled coagulum and is accomplished by stomping, rolling with a stick, bottle or roller, or in Paraguay by perforating the coagulum with a multitude of fine holes. Before coagulation the latex should be thinned (one to two parts of water to two parts of latex) to permit straining of any debris from it. Copper screen should not be used for straining, for copper is detrimental to all types of rubber. Seldom do local peoples use a measured concentration of alum. A small handful of crystals to a few-liter container of latex is about as precise as the measurement ever is. On the large supervised ranches in Paraguay 1¼ tablespoons of alum plus 1¼ tablespoons of salt were used with a liter of water to make a coagulating solution. This solution was poured over the filtered latex and worked in with the fingers until coagulation occurred. The serum left after coagulation was reused with the next batch of latex. Different latices in different parts of Brazil seemed to require different concentrations of alum to effect coagulation. Although alum is available in much of Brazil and a favorite for mangabeira coagulation through most of the interior, graders discouraged its use, feeling that alum-coagulated rubber had a greater tendency to turn tacky. I have seen crude rubber from Maranhão and Paraguay coagulated with alum, however, that remained exposed to air for years without a trace of tackiness.

Salt. Use of salt as a coagulant has most of the advantages and disadvantages of alum. It is not so quick nor thorough in effecting coagulation as is alum, and labor is likely to use excessive amounts which possibly cause accelerated deterioration of the rubber. Coagulation is best done in non-metallic containers, for a blue dye, produced by tannins of the latex reacting with iron, stains the coagulum when it is left for the prolonged period necessary with use of modest quantities of salt. Salt coagulation has been commonly practiced on the Ceará coast, and scatteringly on interior taboleiros in Brazil. At times sea water has provided the salt solution (Boipeba island, Baía). Solutions locally prepared contain one to two cups of salt dissolved per liter of water, one cup of which is used to coagulate a liter of latex.

Acid. Various acids will cause coagulation of mangabeira latex, but results with locally available acids are uncertain, and this method of coagulation is seldom employed where other means are possible. Juices of lemon, lime and various wild fruits have been tried. The sap of caxinguba (*Ficus anthelmintica* ?) is reported useful, but seldom is this wild fig found in association with mangabeira. Oxalic acid was found to give coagulum of good vulcanization and strength qualities, but unfortunately large quantities of this comparatively expensive ingredient must be used, so that the system has never become practical. Sulphuric and hydrochloric acids are reported usable if care is taken, but

even then there is floculation of the coagulum in processing.

Other Chemicals. Other chemical coagulants have never proven practical in possible, however, for it is unknown and unobtainable in the remote districts where mangabeira rubber is produced. The same is true of various other re-



FIGS. 22–24 (*Uppers and Lower left*). Three views of tapping a typical mangabeira tree of the taboleiros near Corumba, Goiaz, Brazil.

Fig. 25 (*Lower right*). Straining mangabeira latex prior to coagulation. Cascavel, Ceará. (*Photos courtesy of Dr. H. C. Cutler*).

production of wild rubber. A chemist assigned to study mangabeira latex coagulation during the war advocated use of ammonium chloride, among other coagulants. Use of this chemical is im-agents; none is suitable unless locally abundant, cheap and simply utilized.

Smoking. The smoking of mangabeira latex by a process similar to that used in connection with *Hevea* latex

from the wild, was stressed for a time, but the tediousness and excessive labor of the process make it unacceptable to mangabeira tappers.

Handling and Marketing

Handling of mangabeira is much more difficult than is that of manicoba. In even a few weeks time the rubber is apt to deteriorate markedly, becoming tacky and inelastic. This appears to be more common with mangabeira from the coastal areas of Brazil, particularly if salt- or alum-coagulated, than with mangabeira from Paraguay or interior Brazil. It was found during the war that mangabeira rubber kept continually moist kept better than rubber racked or otherwise exposed to air. Many dealers kept mangabeira sheet in tanks of water until a few days before shipment. Because of the tendency towards deterioration, quick turnover of mangabeira is advisable. It is a tricky rubber, and its quirks are not always predictable, nor their cause known.

Marketing of mangabeira is similar to that of manicoba. Local buyers or agents purchase or trade from isolated tappers at as low a price as possible. Usually rubber so purchased has an extremely high moisture content (60–70%), and must be further dried or squeezed to attain higher grade status. Grading of mangabeira is largely a question of moisture content, for if the latex has been caught in cups and strained before coagulation, there is little chance of many impurities being present. A series of middlemen eventually send the rubber to the port cities where large exporters distribute it to manufacturing centers. In peace time little demand exists for mangabeira except locally. During the war years production could never be pushed to 1,000 tons annually, and sustained production of even a few hundred tons annually for all of South America would be difficult. Certainly mangabeira can never compete with *Hevea* on the world market, in quantity, quality or price. To the best of my knowledge no mangabeira plantings have ever been made. The tree appears too slow-growing and demands too special an environment to lend itself to plantation practices.

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World Production and Consumption of Millet and Sorghum[1]

Millet and sorghum are important food grains in many foreign countries, but they are almost unknown for this purpose in the United States. World production of these two grains averages almost a third of the production of wheat, almost half of the production of rice, and slightly more than the production of rye. Asia, Africa and the Soviet Union produce most of the millet and sorghum grown in the world.

ELNA ANDERSON

and

JOHN H. MARTIN[2]

U. S. Department of Agriculture

Importance

Millet and sorghum are grown and used as food by millions of the inhabitants of the earth. They are cultivated by more than one-eighth of the farmers in the United States, but are little known to other Americans because they are usually consumed where grown and do not enter in any large volume into international trade. A large part of the millet and sorghum of the world is produced in Asia, Africa and the Soviet Union where most of it is consumed as food. Much of it is grown where the seasons are too short, or where the climate is too hot or too dry, for other grains to succeed well. World production of millet and sorghum for the period 1934–1938 averaged about 50,300,000 short tons annually, compared with 171,000,000 short tons of wheat, 110,300,000 short tons of rice, and 47,500,000 short tons of rye.

Millet and sorghum have come to be looked upon as "poor man's cereals", and some writers refer to them as "inferior" grains. Probably the principal reason for these aspersions is that some kinds of them have a rather strong taste. When people are given free choice, they seem to prefer such cereals as wheat and rice which are bland and mild of taste. Studies of the nutritive value of sorghum and millet show that they compare favorably in this respect with other cereal grains. In some countries the poorer natives sell rice or wheat which command a higher price and consume the cheaper "coarse" grains.

History

Millet and sorghum are among the oldest of the cereals, and in the ancient world they were common bread grains. Millet was used as food in prehistoric times, and little is known concerning its origin. Some students believe that it was the first cultivated crop, having been grown in the so-called Hoe-Age which preceded the Plow-Age. Its use as a food in India, China and Egypt began before there were written records.

In ancient and medieval times millet

[1] Contribution from the Bureau of Agricultural Economics and the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture.

[2] Agricultural Economic Statistician and Senior Agronomist, respectively.

was grown in most of the known world. During the Middle Ages it was one of the principal foods of the poor people of Rome and of Europe generally. During the 19th century millet was gradually superseded in western Europe by wheat, rye, rice, maize and potatoes which usually produce higher yields than does millet. Development of yeast-raised bread was partly responsible for this eclipse in western Europe, for millet does not have some of the qualities required for making a good raised bread. At present, millet's share in world production of cereals is less than in the past, since it has been gradually replaced in most occidental countries by other foods, especially wheat and corn, and, to some extent, by potatoes. Only small quantities are grown now in western Europe where it is used mainly for poultry feed. In eastern Europe millet it still served as a food in the form of porridge and flatbread, or used for making alcoholic drinks. Large quantities are grown and used as food in China, India, Manchuria, Africa and the Soviet Union.

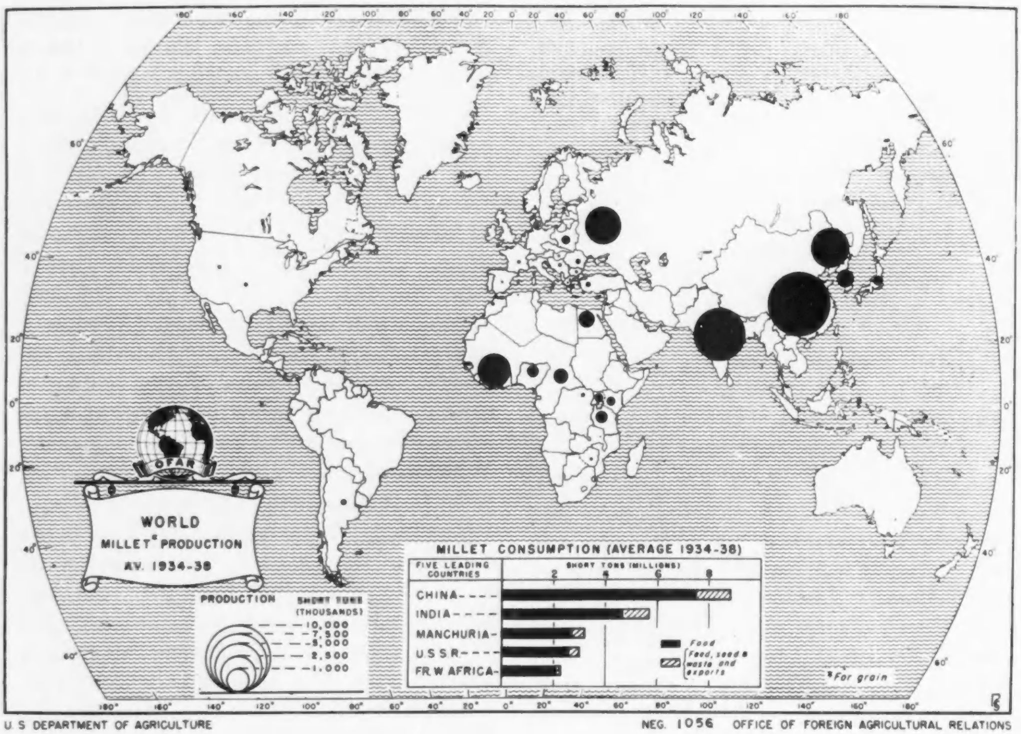


FIG. 1. The annual world production of millet during 1934–1938 averaged about 26 million short tons. More than 22 million tons were consumed as food, and about 1.5 million were fed to poultry and livestock. China, India, Manchuria, the Soviet Union and French West Africa were the principal producing and consuming countries.

Sorghum was grown in Assyria as early as 700 B.C. Pliny wrote that sorghum was brought to Rome from India, and it was long believed that India was its original home. It has not been found growing in a wild state in India, and it is now thought that it originated in Africa. Doubtless, it has been grown in Africa for several thousand years. Sorghum apparently did not

FIG. 2. The open tree-like panicles of Turghai proso, a variety of *Panicum milliaceum* and constituting one of the many forms of millet.

reach China until the 13th century A.D. In recent times sorghum apparently has resisted, better than millet, replacement by other crops. In some areas it has made gains, sometimes at the expense of millet. In India and Manchuria production of sorghum has been greatly expanded in recent years.

FIG. 3. The compact panicle of Early Fortune proso, another variety of *Panicum milliaceum*.

Some Botanical Aspects

Although millets and sorghums are distinct crops and are so recognized by the natives of Asia and Africa, they are often confused in the minds of Europeans. Thus the British introduced the term "millet" to India where now all of the sorghums and millets are grouped as millets by agricultural authorities. In Australia broomcorn, a sorghum, is called "broom millet". A small-seeded sorghum introduced into the West Indies from Africa during the days of slave importation is still grown there under the French name "petit mil" (little millet). In Germany the millets and sorghums bear the name "Hirse" with various prefixes to indicate the particular kind. The sorghums (kaoliangs) of China have often been referred to by English-speaking peoples as "tall millet". Even in the United States one variety of sweet sorghum is named "African millet".

Millets and sorghums have certain characertistics in common. They are all annual, warm weather grasses; are short-day plants, *i.e.*, are stimulated into early flowering by short photoperiods; and sorghum and at least some of the millets are nitropositive, *i.e.*, stimulated to early flowering by ample available nitrogen. Both sorghums and millets have much smaller seeds in proportion to the size of the mature plant than do the small grains and maize. This results in relatively smaller seedlings and consequently seemingly slower growth until the young plants attain some size. Then the growth curve rises sharply. Another characteristic in common is that in germinating, sorghum and at least some of the millets produce only a single seminal root instead of three or

more, as in corn and the small grains. The young plants of both sorghum and millet contain toxic quantities of prussic acid under certain conditions.

Morphologically and taxonomically, millets and sorghums are quite distinct. The sorghums are all members of one genus (*Sorghum*) in one tribe (Andropogoneae) of the grass family, whereas the millets include several genera in two tribes (Chlorideae, finger millet; Paniceae, other millets). Most millets except pearl millet usually range from one to four feet in height. Sorghums may be as short as two feet or as tall as 20 feet. Sorghum is not described in detail here because of an excellent recent article on the genus in this journal[3]. Sorghums include grain sorghum with dry or non-sweet stalks; sorgo or sweet sorghum with abundant sweet juice, grown for forage, sirup, or for "chewing"; broomcorn, grown for its long brush fibers; and Sudan grass and other grass sorghums grown for hay and pasture.

The seeds of some sorghums have a "waxy or glutinous" endosperm, containing only a particular type of branched chain starch called "amylopectin". These varieties are used for making special food delicacies in Asia, and on a small scale for foods, adhesives and industrial products in the United States. Certain varieties of the proso type of millet also have glutinous seeds.

Kinds of Millet

Nearly all grasses, except the common cereal crops of which the seeds have been used for food, sometimes have been called millets. Those most properly regarded as millets belong to six genera: *Panicum*, *Setaria*, *Echinochloa*, *Eleusine*, *Pennisetum* and *Paspalum*. The principal millet species of the large *Panicum* genus are proso (*P. miliaceum* L.), also called "broomcorn millet", "hog millet" and "Hershey millet"; little millet of India (*P. miliare* Lam.); and browntop millet (*P. ramosum* L.) which is sown for feed-

[3] Karper, R. E. and Quinby, J. R., "Sorghum—Its Production, Utilization and Breeding," Economic Botany 1 (4): 355–371. 1947.

FIG. 4. The spike of Ainu (foxtail) millet, a variety of *Setaria italica*, cultivated by the aborigines of Japan.

ing game birds in southeastern United States.

Pasture and hay grasses of the genus *Panicum* include switchgrass (*P. virgatum* L.), widely distributed in the United States; vine-mesquite (*P. obtusum* H.B.K.) and Texas millet (*P. texanum* Buck.) of the southwestern States;

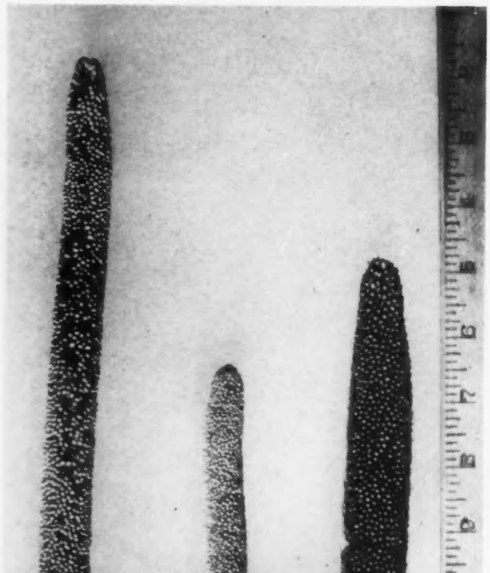


FIG. 5. Spikes of pearl millet, *Pennisetum glaucum.*

Guinea grass (*P. maximum* Jacq.) of Africa; and Para grass (*P. purpurascens* Raddi) of Africa, tropical America and southeastern United States. The seeds of several other species of *Panicum* are gathered for food in India.

Millets of the genus *Panicum* are one to four feet in height, have rather open panicles, and the seeds are slightly flattened. The seeds of proso, which thresh out enclosed in the hulls or glumes, are about 1/10 inch in length. The chaff or glumes of different varieties may be white, cream, yellow, orange, red, gray, green, brown and nearly black. The hulled seed is creamy in color. Some varieties have erect, open, tree-shaped panicles; others have erect, short-branched, compact panicles; while still others have long-branched, nodding panicles. The principal varieties of proso in the United States are Yellow Manitoba, Turghai, Early Fortune, Red Russian, Hansen White Siberian and White French. Hundreds of varieties are grown in other parts of the world.

Foxtail millet (*Setaria italica* (L.) Beauv.) includes such varieties as Common, Hungarian, German or Golden, White Wonder, Siberian and Kursk, grown in the United States. Numerous varieties are grown in China, Manchuria and Russia. The plants are one to four feet in height. The seed is borne in bristly cylindrical spikes which range in length from two to 12 inches. The seeds are more slender and somewhat shorter than those of proso. The hulls which enclose the threshed seed may be yellow, orange, green or gray. The hulled seed is of a creamy color.

Japanese Barnyard millet (*Echinochloa crusgalli frumentacea* (Roxb.) Wight), formerly exploited as "Billion Dollar grass", differs from the grassy weed barnyard grass (*Echinochloa crusgalli* (L.) Beauv.) in having awnless spikelets borne in thick appressed racemes. It is usually three to four feet tall. The spikelets are concave on one

side and are borne on one side of each branch of the rather compact panicles. A related species, *Echinochloa colonum* (L.) Link, is the Shama millet or Jungle rice of India.

Finger millet (*Eleusine coracana* (L.) Gaertn.), also called "ragi", "birds-foot millet", "coracan millet" and "African millet", is cultivated for food in Africa and southern Asia. The plants are two to four feet in height. The spikelets are borne in two rows along one side of the

FIG. 6 (*Upper*). A good crop of foxtail millet (*Setaria italica*) drying somewhere in China, previous to the heads being detached and threshed, and the stalks stored for thorough drying.

FIG. 7 (*Lower*). Foxtail millet growing in semi-arid North China where it is an important crop, providing human food and forage for work animals. (*Photos by courtesy of R. T. Moyer, U. S. Dept. Agr., Off. For. Agr. Rel.*).

rachis of the spike. The two to several spikes, or "fingers", arise at the top of the stem. The straw-colored chaff encloses small white seeds.

Pearl or cattail millet (*Pennisetum glaucum* (L.) R. Br.) is the crop known as "bajra" or "bajri" in India. This large grass plant has stems that range up to ten feet or more in height and an inch in thickness. The stiff cylindric head or spike of pearl millet usually is from eight to 18 inches long and about one inch thick. The heads are similar in size and shape to those of the common cattail found growing in shallow waters, but they have a beaded appearance resulting from the exposed pearly-white seeds. The seeds, which thresh out free from the hulls, are much larger than those of any other millets. Most of the seeds of other millets remain in the hulls during threshing. Pearl millet is related to the perennial Napier grass (*P. purpureum* Schum.), introduced into southeastern United States in 1913.

The koda millet of India, or Ditch millet of New Zealand (*Paspalum scrobiculatum* L.), resembles certain forage grasses of the genus *Paspalum* that are grown in southeastern United States, including Dallis grass, Vasey grass and Bahia grass. The seeds are borne in two rows on one side of the rachis of spike-like racemes.

FIG. 8. Winnowing threshed pearl millet, *Pennisetum glaucum*, in India.

Environmental Requirements for Millet and Sorghum

Perhaps the main reason for the survival of millet and sorghum as important food grains in large sections of the earth is that most varieties produce,

under conditions of intense heat and scanty rainfall, a greater quantity of grain than other cereals produce. Sorghum can remain dormant during a drought and then resume growth when rains come. On the other hand, sorghum also thrives and produces much higher yields under irrigated or high rainfall conditions. Most varieties of millet have the additional advantage that they require only a short growing season. In India, where much depends on when the monsoon arrives, millet is very valuable. If the monsoon comes too late for other spring grains, millet may be planted, and it is almost sure to produce some kind of crop. It is also valuable as a second or catch crop. Another advantage is that seed requirements are low, since the seeds are relatively small. This is important in countries like India and China where many poor people live on the land. Many of them find it difficult to save the grain required for the next season's seeding.

Cattail millet makes a minimum claim on soil, but it requires hot weather. It grows in a dry light soil and thrives on plains that have extended dry periods, such as western Ghats and the plains of Rajputana in India, and in the Sudan near the Sahara. In the United States it is confined largely to the humid areas of the Southeast.

Finger millet is a hardy plant that grows in almost any soil. In contrast with other millets it thrives in a moist climate but does not do well where there are very heavy rains. It grows at an altitude of 6,000 to 7,000 feet on rocky soil in the rainy foothills of the Himalayas.

Proso grows farther north than any other millet. It thrives in southern and central Russia, central Europe, northern India, northern China and Manchuria. It grows very fast and needs relatively little water, but it demands better soil than the millets listed above. It is especially suited to a dry continental climate, such as that of central Asia.

Foxtail millet needs fair soil and moderate temperatures.

Barnyard millet is grown chiefly in Japan. It is adapted to temperate, humid and sub-humid conditions. A relative is the guinea grass, a native of tropical Africa, which grows eight feet tall and yields a nutritious grain.

Production and Consumption[4]

It is difficult to obtain reliable statistics for millet and sorghum because they are grown and consumed principally in Asiatic and African countries where crop reporting has not been developed so well as in Europe and America, and because they do not enter into international trade to any extent. For instance, in India where statistics for most crops are fairly reliable, a large part of the millet and sorghum is grown in the native States where crop statistics are far from complete. In compiling the accompanying tables, official statistics have been used for those countries which publish official figures; when these were not available, unofficial estimates have been included. However, in large areas in Asia and Africa some millet and sorghum are grown and consumed, but no statistics are available. Therefore, the estimates of total production and con-

[4] Many persons in the Department of Agriculture were consulted by Miss Anderson in the preparation of her part of the manuscript, especially O. C. Stine, Assistant Chief, Bureau of Agricultural Economics; H. L. Shantz, Collaborator, Forest Service; Raymond T. Moyer, Naum Jasny, and other members of the Office of Foreign Agricultural Relations; Carleton R. Ball, collaborator, Extension Service; Bernice K. Watt and Annabel L. Merrill, Bureau of Human Nutrition and Home Economics; Charlotte Chatfield, Office of Marketing Services; Louise Stanley, Agricultural Research Administration; and George C. Edler and Thomas J. Kuzelka, Bureau of Agricultural Economics. J. Lossing Buck, writer on Chinese Agriculture, read the manuscript, offered suggestions and expressed satisfaction that the subject of millet and sorghum is receiving attention because of its importance as a food for many people of the world.

TABLE 1

MILLET (GRAIN): PRODUCTION, TRADE AND CONSUMPTION, BY COUNTRIES, AVERAGE 1934–38.

Country	Production	Imports	Exports	Seed and waste	Consumption		
					For feed	For food	
						Total	Per capita
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Pounds*
Asia:							
China	8,867,000[1]	13,840	26,335	620,000	708,000	7,527,000[2]	36
Japan	175,324	9,225[3]	...	22,000	70,000	93,000	3
Korea	693,120[4]	161,096[5]	...	106,000	...	748,000	66
India	5,720,282	434	5,330	572,000	286,000	4,857,000	27
Manchuria	3,206,686	...	176,991	212,000	212,000	2,606,000	135
Turkey	48,760	...	6,969[3]	650	10,450	30,700	4
Africa:							
French Equatorial Africa	435,408[6]	...	...	44,000	...	391,000	223
Algeria	267	4,747	269	30	...	4,700	1
Belgian Congo	19,857[6]	...	...	2,000	...	18,000	4
Cameroon	319,667[3]	...	...	32,000	...	288,000	229
Egypt	469,090	4	3,398[3]	46,400	...	419,300	51
French W. Africa	2,243,548[7]	31[8]	848[7]	224,300	...	2,018,400	270
French Morocco	7,958	543[4, 7]	3,214[7]	480	...	4,800	1
Kenya	131,701[6]	177[9]	26[9]	13,400	...	118,500	70
Madagascar	618[3]	10[7]	...	60	...	570	[10]
Tanganyika	321,706[6]	...	211[3]	32,200	...	289,300	110
Uganda	155,308[6]	59[9]	8[9]	15,500	...	139,900	75
Nyasaland	231	...	...	20	...	210	[10]
So. Rhodesia	11,706[11]	...	...	1,200	...	10,500	15
Europe:							
Bulgaria	8,095	...	1,466	850	2,000	3,800	1
Austria	6,995[3]	517[12]	4[3, 13]	700	6,800	...	...
Czechoslovakia	3,097	6,819	...	400	9,500	...	...
France	10,039	18,000[14]	400	1,200	24,000	2,400	[10]
Greece	1,845	129[15]	34[15]	200	875	865	[10]
Hungary	8,543	256[4]	1,959	800	5,500	500	[10]
Poland	113,655	...	...	11,000	1,000	101,700	6
Rumania	41,546	...	6,725[7]	3,500	27,300	4,000	[10]
U.S.S.R.	3,033,155	...	1,801[7]	303,100	136,000	2,592,000	30
Spain	4,582[4]	107[4, 16]	...	450	2,100	2,100	[10]
Yugoslavia	29,240	4[3]	1,039	2,410	25,400	400	[10]
Australia:	544[3]	78[4]	57	60	505	...	...
South America:							
Argentina	60,186[6]	...	26,947	6,000	...	27,000	4
North America:							
United States	15,000	2,621	...	1,500	16,000	...	...
Total	26,164,759	218,697	264,031	2,276,410	1,543,430	22,299,645[17]	

TABLE 1

Production estimates for China from the Statistical Abstract of China, 1940; for Manchuria, from 6th Report on Progress in Manchuria to 1939 (So. Machurian Railway Co.). Estimates for British India and Burma from Estimates of Area and Yield of the Principal Crops in India, Vol. I and Vol. II, combined with estimates for the Indian States calculated from the reported area estimates. Estimates for the Belgian Congo, Kenya, Tanganyika, Nyasaland, Southern Rhodesia and Uganda calculated from acreage estimates by H. L. Shantz in Economic Geography, June, 1940. Estimates for Korea from cable by O. L. Dawson, Agricultural Attaché, Shanghai, February 15, 1939; U.S.S.R., from official publications. All others from International Institute of Agriculture. Consumption for China based on percentage distribution of crops for different uses from China Crop Report of the National Agricultural Research Bureau of Nanking, Vol. VI, No.

sumption given here are conservative, and actual production and consumption may be considerably larger. Tables 1 and 2 summarize the information that is available concerning world production and consumption of millet and sorghum.

About 90 percent of the world's crop of millet and sorghum is grown in China, India, Manchuria, French West Africa and the Soviet Union; China and India together produce about 60 percent. World production of millet is somewhat larger than the production of sorghum, and is more widely diffused. Of the millet crop 88 percent is grown in the five countries listed, whereas 90 percent of the sorghum crop is grown in the first four (Tables 1 and 2).

It is estimated that average world consumption of millet for food during the period 1934–1938, was 22,300,000 short tons, or 85 percent of the total crop. About six percent, or 1,500,000 short tons, was fed to livestock and fowls. A smaller proportion of the sorghum crop was used as food, about 18,100,000 short tons, or 75 percent, and consumption as feed was about 3,900,000 short tons, or 16 percent.

Where Grown

China. Millet and sorghum are staple foods in China, and they are grown there extensively. It is generally believed that the Chinese live on rice, but it is only in southern China that rice is the principal food of the people. In northern China wheat, millet and sorghum are the staples.

Sorghum is grown in many parts of China and is called "kaoliang" which means, literally, "high grain". In the central and western sections of China it is known as "shu-shu". It is estimated that 45 to 55 percent of koaliang grain utilized on farms is used for foods, and about 20 percent for feed. Some of the grain is used in making wine and some for brandy. Kaoliang stalks, which often grow 10 to 12 feet tall, are used in a variety of ways—for building fences and bridges, the walls, partitions and roofs of farm buildings, for weaving mats and baskets, and making paper, fibers and brooms. In some parts of China there is little or no wood or coal, and large quantities of kaoliang stubble are used for fuel.

Kaoliang grain is ground into flour and groats which are consumed as bread or porridge. The well-to-do use kaoliang mixed with a large percentage of wheat flour for bread-making. Alcoholic drinks made from kaoliang are favorites among the Chinese people.

Although kaoliang is grown over most

10, October 1938. For the U.S.S.R., consumption was calculated on the basis of percentages reported officially. For all other countries, consumption is production less net exports, less seed and waste; estimates of seed and waste, feed and food made on the basis of unofficial estimates and information received from members of the Office of Foreign Agricultural Relations.

[1] 1934–37 average. The estimate for 1938 is incomplete because of war conditions.
[2] Includes 880,000 short tons for "other uses" such as alcoholic drinks.
[3] 4-year average.
[4] 2-year average.
[5] Imports from Manchukuo and China only.
[6] Estimate for 1 year only.
[7] 3-year average.
[8] Imports from Algeria and France only.
[9] Estimated from trade figures for Kenya and Uganda.
[10] Less than 0.5 pounds.
[11] Half of the amount estimated for millet and sorghum.
[12] Imports from Manchukuo, Egypt, and Yugoslavia only.
[13] Exports to Germany, Yugoslavia, and Czechoslovakia only.
[14] Half of imports of dari, millet, and alpiste, which are not reported separately.
[15] 1930–35 average imports or exports.
[16] Imports from France only.
[17] Cross total will not check due to rounding.

TABLE 2

SORGHUM (GRAIN): PRODUCTION, TRADE AND CONSUMPTION, BY COUNTRIES, AVERAGE 1934–38

Country	Production	Imports	Exports	Seed and waste	Consumption		
					For feed	For food	
						Total	Per capita
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Pounds*
Asia:							
China	7,648,000[1]		4,812	535,000	1,529,000	5,579,000[2]	27
Burma	67,872		17[3]	6,800	3,400	57,700	7
India	7,540,236	434[4]	5,330[4]	754,000	377,000	6,404,000	35
Manchuria	4,420,393		176,916	297,000	636,000	3,310,000	171
Syria and Lebanon	68,734			6,900	30,900	30,900	17
Africa:							
Algeria	5,766[3]			600		5,200	1
Belgian Congo	13,608[5]			1,500		12,000	2
Anglo-Egyptian Sudan	376,488[5]			37,600		338,900	110
French W. Africa	2,180,000[6]			211,500		1,968,500	263
Dahomey	1,000,000			100,000		900,000	
Ivory Coast	245,000			25,000		220,000	
Senegal	650,000			58,000		592,000	
Other	285,000			28,500		256,500	
French Morocco	40,065[3]		1,480[3]	3,900		34,700	11
Tunisia	3,031[6]			300		2,700	2
Uganda	50,085[2]			5,000		45,000	24
Kenya	50,000			4,000		46,000	27
Union of S. Africa	116,747[7]		323	12,600		103,800	21
So. Rhodesia	11,706[8]			1,200		10,500	15
Europe:							
U.S.S.R.	160,000			15,000	35,000	110,000	1
Hungary	21,423			2,500	9,500	9,400	2
Rumania	25,373		6,725[3]	2,000	15,700	900	[9]
Spain	823[10]			100	600	100	
Yugoslavia	3,568		2,700	90	710	100	
South America:							
Uruguay	404[11]			40	360		
North America:							
United States	1,367,783			140,000	1,227,783		
Total	24,172,105	434	198,303	2,037,630	3,865,953	18,069,400[12]	

TABLE 2

Production estimates for the United States from reports of the Crop Reporting Board, United States Department of Agriculture; for China, from the Statistical Abstract of China, 1940; for Manchuria, from 6th Report on Progress in Manchuria to 1939 (So. Manchurian Railway Co.). Estimates for British India and Burma from Estimates of Area and Yield of the Principal Crops in India, Vol. 1 and Vol. 2, combined with estimates for the Indian States calculated from the reported area estimates. Estimates for the Belgian Congo, Anglo-Egyptian Sudan and Uganda calculated from acreage estimated by H. L. Shantz in Economic Geography, June, 1940; all others from International Institute of Agriculture. Trade figures from official publications. Consumption for China based on percentage distribution of crops for different uses from China Crop Report of the National Agricultural Research Bureau, Vol. 6, No. 10, October 1938. For the United States, consumption for feed is production minus seed requirements. Consumption for all other countries is production less net exports less seed and waste; estimates of seed and waste, feed, and food were made on the basis of unofficial estimates and information received from members of the Office of Foreign Agricultural Relations.

[1] 1934–37 average. The estimate for 1938 is incomplete because of war conditions.

of central, west and north China, and in Manchuria, the chief producing provinces are Shantung, Honan and Hopei, where about 60 percent of the crop is produced. In some parts of China where the climate is favorable, two or three crops are grown each year. One crop is kaoliang or some kind of millet, depending on the rainfall. Kaoliang is grown extensively in southern Manchuria, although in recent years soybeans have crowded it out in many areas. In southern Manchuria millet is planted in May. A furrow is made in each middle between rows of the previous year and a man following the plow, drops seed from a gourd-kaoliang stalk planter. Soil is kicked into the furrow to cover the seed and then compacted with an oval stone roller drawn by a donkey. The harvested millet is placed on the threshing floor or ground with the heads toward the center and then threshed with stone rollers. It is used as flour for bread and cakes, or as paste from pounded soaked seed, or as boiled gruel. Acreage of wheat has increased, but kaoliang remains an important food of the people. In certain sections, such as northern Hopei, kaoliang is grown extensively. The leaves are used for green feed, the grain for food, feed for animals, and for making alcoholic drinks.

The kinds of millet cultivated in China are mainly foxtail millet, proso and finger millet, but no cattail millet. Foxtail millet, by far the most important, is grown in Hopei, Shantung, Honan and Shansi, and in north China generally. This hardy plant, which grows in many regions where other cereals do not thrive, is found in the mountainous sections as well as on the plains of many parts of China. Proso is grown principally in Shantung, Hopei, Shansi and Kansu. Sometimes it is used in making a kind of wine. Finger millet is grown mainly in Shantung, Shansi and Szechwan, but not extensively. It is often used for beer making for which it is well suited.

India. Millet and sorghum are among India's chief food crops; about 20 percent of the cropland is devoted to their cultivation. Production of all millet and sorghum averaged 13,260,000 short tons in the period 1934–1938, compared with 10,980,000 short tons of wheat and 28,533,000 short tons of rice. Large quantities of wheat and rice were exported, but practically none of the millet and sorghum. These are consumed within the country, mostly as food. They are staple foods of a large part of the population of India. The stalks, straw and some of the grain furnish feed for animals and fowls.

The official statistics of acreage and production of millet and sorghum for India include only estimates for sorghum ("jowar" or "cholam"), cattail millet ("bajra") and finger millet ("ragi"), which are the principal varieties grown. Several other millets are grown, but there are no acreage and production estimates for them. Jowar is the most important of the three crops mentioned above, the production averaging 7,540,000 short tons for the years

[2] Includes 2,200,000 short tons for "other uses" such as alcoholic drinks.
[3] 3-year average.
[4] Half of the figure for jowar and bajra.
[5] Estimate for 1 year only.
[6] Rough unofficial estimate.
[7] Half of the amount reported for maize and sorghum.
[8] Half of the amount estimated for millet and sorghum.
[9] Less than 0.5 pounds.
[10] 2-year average.
[11] 4-year average.
[12] Cross total will not check due to rounding.

1934–1938, compared with 3,140,000 short tons of bajra, and 2,580,000 short tons of ragi.

A number of the Indian, or native States report only acreage of sorghum and millet, and others do not report at all, although it is known that some of these States produce one or both crops. Rough estimates of production of both crops have been made for the native States, based on incomplete official acreage estimates for the native States and yields in British India. Although the yields in British India are probably

FIG. 9. Irrigated grain sorghum in Ivory Coast, West Africa. (*Photo by courtesy of the Ministère des Colonies, Paris*).

higher than yields in the native States, this is counterbalanced to some extent by the incompleteness of the acreage estimates for the native States. These cereals are staple foods of the people in most of the native States.

Some kind of millet or sorghum is grown in most parts of India,[5] but the principal producing sections are central and southeastern India where the climate is especially suitable. Heavy monsoon rains furnish necessary moisture during the planting season at the beginning of summer, and the lack of moisture in later months does not discourage development of millet and sorghum, whereas wheat and rice do not thrive. If the monsoon is late in arriving, cattail millet is substituted for sorghum, provided seed is available, since it can produce some kind of crop with a small amount of moisture. If the monsoon fails entirely, a famine is inevitable. In recent years these famines have been much less severe because of importation of food supplies by the Government.

FIG. 10. Sorghum and cotton grown in alternate rows in French Sudan near the Niger river. (*Courtesy of the Ministère des Colonies, Paris*).

Practically all of the sorghum is consumed locally, some of it as animal feed. It is especially valuable to the agricultural population because it yields as much grain per acre as wheat and several times as much fodder.

Sorghum is grown in most parts of India but principally on the Deccan Plateau and in central India, as it resists drought well. About 60 percent of the acreage is in British India and about

[5] An agricultural aphorism from the United Provinces: "The yield is very heavy when sun hemp is sown thickly, jowar at a distance of frogs hopping, and bajra at paces length."

40 percent in the Indian States, according to the statistics published by the Department of Commercial Intelligence and Statistics of India, which are incomplete, especially for the Indian States. The largest acreages in British India are in Bombay, Central Provinces, and Berar, Madras, and the United Provinces. In the Indian States the chief sorghum growing States are Hyderabad, Rajputana and Gwalior. A large sorghum area on the lower banks of the Indus is irrigated, but in most sections the crop is grown without irrigation.

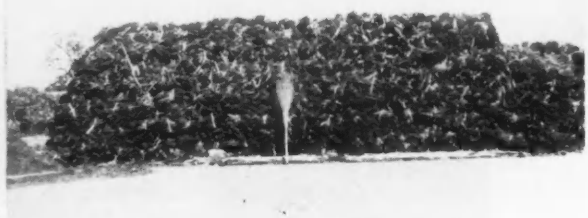


FIG. 11 (*Upper left*). Kaoliang, *Sorghum vulgare* var. *nervosum*, in Manchuria.

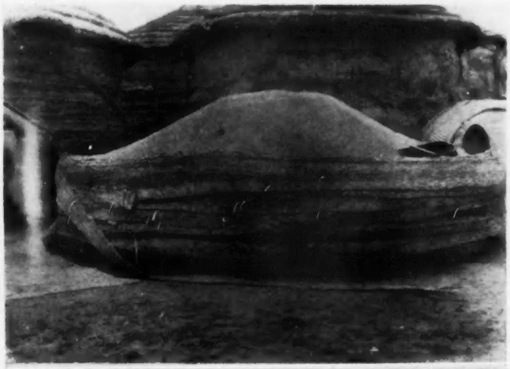
FIG. 12 (*Upper right*). The tunhula, made from a kaoliang stalk and a gourd, is used in Manchuria for sowing millet and kaoliang.

FIG. 13 (*Lower left*). Millet being planted in rows by hand in Manchuria.

FIG. 14 (*Lower right*). A pile of kaoliang heads in Manchuria.

First in importance among the millets of India is cattail millet, or "bajra". No other cereal grows so well in hot dry regions. Most of it is grown in the dry western section where it is the principal food of the people. There are two chief

districts for the cultivation of cattail millet, one in Bombay, Rajputana, and the adjoining Ganges plains, the other in the dry section of western Ghats and in Madras. This particular millet thrives better than does sorghum along the lower Indus plains where there is very little rain, but it is not grown far-

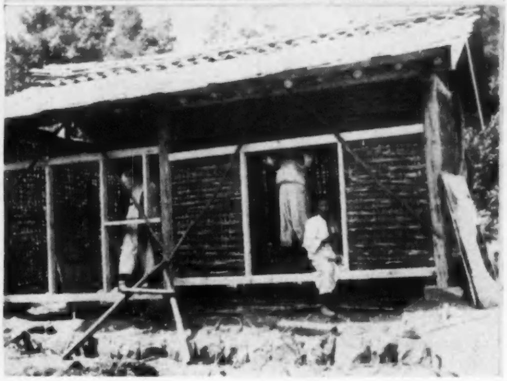


FIG. 15 (*Upper left*). Threshing kaoliang with a stone roller in Manchuria.
FIG. 16 (*Upper right*). Bins of millet in Manchuria made of rice straw, some of the walls plastered with mud.
FIG. 17 (*Lower left*). Women flailing millet in Korea.
FIG. 18 (*Lower right*). Building a house inKorea with woven kaoliang stalks for walls.

ther south along the coast where rainfall is more abundant. It appears as far south as the southern tip of the peninsula where it is sometimes grown as a winter crop.

Finger millet, or "ragi", next in importance among the millets of India, is grown mainly in southern India where it is used as a bread grain and for making cakes and puddings. More than half of the acreage of finger millet is in Madras and vicinity, and practically all of the remaining acreage is in the native States, mostly Mysore. It appears to thrive in the same climate as does rice and is usually found in India where rice grows. Damp mountain slopes seem to be especially favorable. In some dry sections it is grown under irrigation. It is sometimes sown between the rows of maize which often fails to produce a crop. In this case the millet produces a crop of some sort. Finger millet is seeded following the rainy season, or the seed is sown in May in irrigated beds and the young plants are transplanted to fields at the beginning of the rainy season.

In Gujarat it is grown in alluvial soil and irrigated by flood water, and is often grown as a garden vegetable, in which case the unripe ears are eaten. In the interior, finger millet is planted on the eastern slope of the Ghats and up to the edge of the Deccan plains. On the damp west coast it is supplanted by rice. In south India, in Madras and Mysore, where finger millet occupies two-thirds of the planted acreage, the damp climate is especially favorable for its growth. Sowing and harvesting are dependent on the trade winds. With irrigation a crop may be sown any time of year when water is available.

Fig. 19. Sudan grass (*Sorghum vulgare* var. *sudanensis*) (left) and Kursk millet (right), a form of foxtail millet (*Setaria italica*), growing adjacent to one another in South Dakota and showing the difference in size of plants, which accounts for the Sudan grass producing more hay. (*Courtesy of the U. S. Bur. Pl. Ind., Soils, and Agr. Eng.*)

Although official statistics include only bajra and ragi, many other kinds of millet are grown in India. Foxtail millet is not grown to any great extent, although the natives are very fond of it. The Hindus regard it as a holy food, and it is often prescribed as a food for invalids. It is the principal grain in a small section of the highlands of Mysore where the climate seems to be especially agreeable for it. Most of it is grown as a summer crop. Proso is grown in certain sections, mostly in southern India, south of the Kistna River, where it is one of the principal foods. Other kinds of millet are grown in many parts of India, and although they are important locally, the total production for the country is not large.

Central Asia and the U.S.S.R. Another chief millet-producing and consuming area is central Asia and Soviet Russia where proso, or bread millet, is widely grown. It is grown in the south-

ern half of Soviet Russia and is a staple food throughout the country. In a broad belt running through central and southern Russia it is one of the important crops. It is eaten mostly in the form of a thick porridge called "kasha". The nomadic peoples, the Mongolians and the Kirgis, are very fond of millet as a food, and as a crop it suits their methods of culture. Many sections have little rainfall but receive water for some type of irrigation from mountain streams. Most of the sorghum production is in the Ukraine, Turkmen and Ufibek, and the acreage is small. In the Ukraine sorghum is used principally as feed for cattle, but in Turkmen and Uzbek it is used mainly for food.

In Arabia, Syria, Iran, Irak and Afghanistan millet has been cultivated for many centuries. Although it is of much less importance today than formerly, a considerable quantity is grown, and it is a staple food of many of the poor people. In Iran, proso, foxtail millet and some cattail millet are grown in the northeastern, southern and western parts, and sorghum grows well in upper Irak. Cattail millet is found in southwestern Arabia, and some sorghum is grown farther north. In Syria sorghum is grown instead of wheat if the rainfall happens to be slight; in Palestine a considerable quantity is harvested.

Africa. Africa has a great sorghum belt running across the continent south of the Sahara from the Atlantic Ocean through French Guinea, the Ivory Coast, Upper Volta, Dahomey, Nigeria, French Equatorial Africa, Belgium Congo, southern Anglo-Egyptian Sudan, Uganda, Ethiopia and British Somaliland. Extensive plantings are found also in Kenya, Tanganyika, northern and southern Rhodesia, and Mozambique. In fact, sorghum is grown in most parts of Africa, but the crop is of less importance in the sections not mentioned. No production statistics are available for many of these countries. Cattail millet and finger millet, often designated as *Pennisetum* and *Eleusine* in literature of Africa, are also grown in many parts of Africa. In most instances, methods of cultivation are extremely primitive.

Sorghum is grown in Morocco, Tunisia and Algeria but not in large quantities. Morocco exports sorghum stalks to Algeria where they are used in the broom industry. Some of the grain is exported to Europe as bird and chicken feed. Millet and sorghum are produced in the oases of the Sahara where a good deal of excellent agricultural land is watered by springs. The grain serves as food for the natives, and the stalks provide fuel and building material. Finger millet is grown in many sections of Ethiopia and Somaliland where it is used for food and for making beer.

Sorghum is the predominant crop of the savannah of the Sudan, and millet is widely grown. In certain sections of the Sudan, cattail millet predominates, and finger millet is the chief crop in other sections where it is the daily food of the people in the form of porridge and beer. Cattail millet thrives in French Equatorial Africa; in Nigeria sorghum yields a rich harvest. In the dry rocky soil near Lake Chad the only crop that does well is cattail millet. Farther south where the soil is better and moisture more plentiful, sorghum reappears. The savannah is well suited to the cultivation of sorghum and corn, and sorghum is again the staple food of the natives as porridge, dumplings and beer. In a dry year when the crop is poor they have porridge but no beer. Also, in a dry year when sorghum does not bring forth a crop, cattail millet may be sown as a second crop, as it requires less rainfall. The climate in tropical East Africa, because of the monsoon rains and dry periods, is favorable for the cultivation of millet and sorghum. In some sections

maize is grown, but sorghum is cultivated more generally. In recent years cattail millet and finger millet have not been produced in as large quantities as they were formerly.

In the subtropical Union of South Africa, sorghum is grown in large quantities which are mostly consumed within the country by both natives and whites. The principal food of the natives is sorghum, or "kafir corn", which is eaten after it has been soaked in water. It is also used in making beer and is fed green to livestock. White and yellow grain varieties are used for food, while the red or brown bitter-seeded varieties are used for making beer by all African natives. Thus no hops are needed to furnish the bitterness cherished by beer drinkers everywhere. In Madagascar sorghum is cultivated in the dry western part.

In Egypt, near the Nile, sorghum grows very well, but cotton has crowded it out, except as a second or third crop, which keeps the cotton land well cultivated. Sorghum is grown in Ethiopia and is made into flour for porridge. Finger millet is also grown and is used for porridge and beer-making. The climate of Anglo-Egyptian Sudan is favorable for the cultivation of millet and sorghum which are the most important crops of the savannah. Sorghum, especially, is grown in large quantities and is the staple food of the natives.

Europe. Millet has now little of its former eminence as a cereal grain in Europe except in Soviet Russia where proso millet is grown and used mainly for porridge or for flat bread. In recent years not much has been grown in Europe outside the Soviet Union, Rumania, Poland and Yugoslavia. Small amounts are grown in France, Germany, Bulgaria, Austria, Czechoslovakia and Hungary. In these countries it is used chiefly for feed for animals and fowls, and for making beer.

In Rumania most of the plantings are of cattail millet and are in the Danube plains. It is used mainly for feed, but is still utilized in some localities for bread making. The Bulgarians make a favorite kind of beer from their millet. In Germany millet has almost disappeared. What is grown is proso which is found in southern and eastern Germany. Considerable quantities of cattail millet were grown in France until the end of the last century when production averaged about 575,000 tons, but little is grown now. Small quantities are grown in Spain where in the last century it was a more important grain.

Some sorghum is cultivated in Europe. It is used for food and feed in the Soviet Union and principally for chicken feed in other countries. Broomcorn is grown in Italy, Hungary and France.

United States. The United States consumed about 1,200,000 short tons of sorghum grain as feed and none as food during the period 1934–1938. Sorghum was brought to the United States from Africa and India about the middle of the last century, and during the period 1934–1939 was harvested on about 12 million acres of land, of which four million acres were harvested for grain. The remaining 8 million acres were harvested for fodder and silage, and a little was used for making sirup. Less than 2 percent of the crop is used for making sirup, which is the only food product of any note that was made from sorghum in this country before the recent starch and dextrose factories were established.

In the 1890's, and previous to 1920, kafir meal was used as food occasionally in Kansas and other States, especially during a drought.

Most of the sorghum in the United States is produced in the southwestern States, especially Texas, Oklahoma, Kansas and adjacent States, where it has special value because of its resistance to drought and heat. It is grown also on

irrigated land in the hot interior valleys of California and Arizona. Sorgo for sirup is grown mostly in the southern States. Broomcorn is grown in Oklahoma, Colorado, New Mexico, Texas, Kansas and Illinois.

Millet is a minor crop in the United States. Roughly about 30,000,000 pounds of seed, mostly proso, are produced, which is used as poultry feed, in birdseed mixtures, as livestock feed and for seed. Proso is grown in North Dakota, South Dakota and Colorado. In general, other cereals yield more grain than does proso in the United States. Foxtail millet is grown for hay in many States but only on a small scale. Barnyard or Japanese millet is grown sparingly for hay in Pennsylvania, New York, Iowa and occasionally elsewhere.

Proso is sown in the United States with a grain drill in late May, June or early July, at the rate of 20 to 40 pounds per acre. It is ready for harvest about 60 to 75 days after seeding, but ripening is not uniform. The seeds in the tips of the earlier heads often are dead ripe and have shattered out before the lower seeds and later panicles are mature. The stems and panicle branches are still green when the seeds ripen. This irregular ripening usually precludes safe harvesting by direct combining. Most of the crop is cut by a swather which permits the crop to cure in windrows on the cut stubble. The crop is then gathered and threshed by a combine with a pickup attachment. Sometimes it is cut with a binder, cured in long slender shocks and then threshed.

Foxtail millet usually is sown as a catch crop in May or June, with a grain drill, at a seeding rate of 15 to 30 pounds per acre. It is cut for hay when the heads are in bloom. The seed crop is harvested with a combine or binder. In western Texas and eastern New Mexico it is usually planted at a rate of about four pounds per acre in cultivated rows three feet or more apart for seed production. Formerly, foxtail millet was an important hay crop in the northern and central States.

Pearl millet may be sown with a drill for hay or pasture or planted in cultivated rows for pasture or silage. It is planted in the spring usually in rows four feet apart at a rate of about four pounds per acre. It is confined chiefly to the southeastern States.

Nutritive Value

The mass of the population in India and China eats the cereal that can be grown locally and cheaply. In India many live mainly on millet and sorghum. In China the cereals consumed by the ordinary people are millet, sorghum, wheat and corn in the north, wheat and rice in the central region, and rice in the south. Much has been written about the insufficiency of certain nutrients in the diets of large segments of the population of China and India, and, in many of these reports, millet and sorghum are classed as "inferior" grains.

Studies of the nutritive value of millet and sorghum as compared with that of other cereal grains show that they are, in general, somewhat lower in protein content than wheat and higher in fat content than wheat and rye. They have a higher protein and fat content than rice (Tables 3, 4, 5). The mineral content of most millets is higher than that of sorghum, wheat, rice and rye, but not of soybeans. Millet has a larger percentage of indigestible fiber than most cereals because the seeds are enclosed in hulls. There is good indication that millet is a rich source of thiamine and might be expected to contain small amounts of other B-vitamins.

Studies of diets in northern China, where millet is a staple food, show a deficiency of thiamine much less frequently than the diets in south China where milled rice is the principal cereal con-

sumed. The milling of rice removes most of its thiamine and accounts for the lack of that vitamin in the diet of the poor in south China. Millet is used as a whole-grain cereal and furnishes thiamine in generous amounts.

On the other hand, certain customs in China improve the nutritive value of the diet. In northern China millet and sorghum are mixed with other cereals or legumes. The proteins of such mixtures show a better balance from the nutri-

TABLE 3

AVERAGE COMPOSITION OF CERTAIN GRAINS AND SOYBEANS

Commodity	Average composition				
	Protein	Fat	Fiber	N-free extract[1]	Mineral matter
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Foxtail millet	12.1	4.1	8.6	60.7	3.6
Proso	11.9	3.4	8.1	63.7	3.3
Japanese millet	10.6	4.9	14.6	54.7	5.0
Milo (grain sorghum)	11.3	2.9	2.2	71.3	1.7
Kaoliang grain	10.5	4.1	1.6	71.8	1.9
Wheat, average all types	13.2	1.9	2.6	69.9	1.9
Rice (rough)	7.9	1.8	9.0	64.9	5.2
Rye	12.6	1.7	2.4	70.9	1.9
Soybeans	37.9	18.0	5.0	24.5	4.6

Compiled from "Feeds and Feeding," by F. B. Morrison, 1948.
[1] Carbohydrate except fiber.

TABLE 4

COMPOSITION OF CERTAIN AFRICAN MILLETS AND SORGHUM

Grain	Water	Crude protein	Ether expressed as fat	Fiber	Carbohydrate (N-free extract)
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Gray millet	11.2	8.2	4.0	1.2	73.4
Pearl millet					
Sample 1, "Mawali"	10.6	12.47	5.0	2.8	67.13
Sample 2	12.67	9.78	3.61	1.98	70.43
Sample 3	9.4	13.7	5.1	2.1	67.7
Finger millet	10.3	5.4	1.5	3.4	76.9
Average	10.83	9.91	3.84	2.30	71.11
Sorghum					
Durra	8.45	13.06	3.3	1.03	72.45
White kafir					
Sample 1	11.93	9.79	3.22	1.27	72.50
Sample 2	8.45	13.06	3.30	1.03	72.45
Sample 3	12.8	9.9	3.4	1.3	71.0
Red kafir					
Sample 1	12.0	10.83	3.37	1.28	71.01
Sample 2	10.0	11.2	2.8	1.8	72.1
Sample 3	13.5	11.1	3.7	1.4	68.9
Mixed kafir	11.73	10.01	3.06	1.14	72.58
Average	11.11	11.12	3.27	1.28	71.62

Compiled from "Food and Nutrition of African Natives," International Institute of African Languages and Cultures, London, Memo XIII, 1937.

TABLE 5

COMPOSITION AND FUEL VALUE OF CERTAIN CHINESE AGRICULTURAL PRODUCTS

Agricultural product	Water	Protein	Fat	Ash	Crude fiber	Carbo-hydrates	Caloric value
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Millet							
Foxtail	10.5	9.7	1.7	1.4	0.1	76.6	361
Foxtail	9.5	9.7	4.2	1.8	0.8	74.0	372
Proso							
Glutinous	8.5	10.9	3.4	1.6	1.0	74.6	372
Glutinous	10.6	9.7	0.9	1.0	0.9	76.9	355
Non-glutinous	15.8	10.5	0.9	1.2	0.9	70.7	333
Finger	8.5	5.8	5.8	3.6	2.0	74.3	373
Kaoliang (grain sorghum)							
Yellow	5.6	9.7	4.1	1.1	1.5	78.0	388
Red	12.1	8.0	4.2	1.3	1.8	72.6	360
"	9.0	9.5	4.7	2.5	1.8	72.5	370
White	13.7	11.9	5.0	3.0	1.6	64.8	352
"	3.7	9.3	5.0	1.5	0.4	80.1	402
Wheat (whole)	10.5	12.4	1.4	2.5	2.4	70.8	345
"	7.8	11.5	1.8	2.8	1.1	75.0	362
Rice (whole)	14.4	9.9	0.9	1.5	0.8	72.5	338
High grade	10.1	9.6	0.2	0.3	0.2	79.6	359
Middle grade	11.0	8.5	0.3	0.6	0.5	79.1	353
Low grade	11.9	7.3	0.4	1.0	0.7	78.7	348
Glutinous	12.4	6.5	0.2	1.1	0.4	79.4	345
Soybeans							
Black							
1. *Glycine max.*	8.4	42.9	12.6	3.9	6.2	26.0	388
2. Large	8.0	51.3	16.6	4.3	3.6	16.2	419
3. Small	7.8	49.8	12.1	4.6	6.8	18.9	384
Green	6.4	37.3	18.3	5.0	3.4	29.6	432
Yellow	8.8	39.2	17.4	5.0	4.2	25.4	415
Cowpeas (*Vigna sinensis*)							
1. Sample 1	10.3	21.3	2.2	3.4	4.3	58.5	339
2. Sample 2	9.1	22.6	2.2	3.5	4.2	58.4	344

Compiled from Analyses of Chinese Food Materials by W. H. Adolph, Philippine Journal of Science, July 1926; and Nutritive Value of Chinese Foods by Hsien Wu, Chinese Journal of Physiology, Report Series 1928, No. 1.

tional standpoint. A recommended mixture is maize, millet and soybeans.[6] The use of sprouted millet also adds nutrients to the Chinese diet. Good as these customs are they do not take care of all of the deficiencies of needed nutrients.

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[6] See William H. Adolph and Fa-Wu Cheng, "The Biological Value of Mixed Cereal Proteins," Chinese Journal of Physiology, August 15, 1935, pp. 245–252.

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Utilization Abstract

Cortisone from Yams. One of the most important recent medical discoveries is that of treating rheumatoid arthritic victims with cortisone, known also as Compound E, an adrenal hormone which is now being obtained synthetically from animal bile. Forty head of cattle are needed to provide the cortisone requirements of one patient for one day, and the cost is now reported to be $5,670 per ounce. Other and less expensive sources of the drug are consequently being sought, and attention is being focussed on plants. The seeds of an African plant, *Strophanthus sarmentosus*, are regarded as providing an unlimited source of raw material for cortisone, and there is now a commission from the U. S. Public Health Service and Department of Agriculture investigating the possibilities of this source in Liberia. The important principle in *Strophanthus* is known as "sarmentogenin" and can be converted into cortisone through 20 steps of conversion, an improvement on the 37 steps needed for cattle bile acid.

A recent discovery has centered attention on tropical American yams, some of which grow in Arizona, New Mexico, Texas and Mexico. From these plants Dr. R. E. Marker, former Professor of Organic Chemistry at Pennsylvania State College, has isolated a material which he has named 'botogenin' and which is looked upon as a possibly very important indigenous and immediately available source of raw material for synthesis of cortisone. (*N. Y. Times, 8/28/49*).

Plant Growth–Regulators

Large-scale use of plant growth-regulating chemicals, unheard of ten years ago, has fostered a multimillion dollar business. In 1948, 27 1/2 million pounds of 2,4-D, once used only in minute doses for laboratory work, were manufactured for agricultural use, primarily in weed eradication. Naphthaleneacetic acid and other compounds are used in smaller but continually increasing quantities in regulating other phases of plant development, wholly apart from nutritional needs supplied by fertilizers.

R. L. WEINTRAUB AND A. G. NORMAN

Camp Detrick, Frederick, Md.

Introduction

The list of chemicals finding uses in agriculture has been lengthened considerably in the past few years by the discovery of a variety of synthetic compounds which possess the property of affecting the growth of plants in some way. The uses for these compounds are surprisingly diverse and are being added to constantly as more becomes known about the nature of the responses which they induce. In contrast to the indirect effects of insecticides or fungicides that serve merely to protect from injury, these compounds act directly upon the plant or the crop, but in a different sense to fertilizer materials that supply major or minor nutrient elements. Although not required for growth, they are capable of regulating growth in some part or parts of the plant. The rapid development and widespread adoption of 2,4-dichlorophenoxyacetic acid, or 2,4-D, as a herbicide have perhaps given the impression that this class of substances will find its main outlet in weed eradication or weed control. While it is undoubtedly true that herbicidal uses will be of great importance and perhaps may provide the greatest volume of business to the chemical industry, it is to be emphasized that chemicals possessing plant growth-regulating activity should not be classified only as herbicides, and even as herbicides they have little in common with the contact herbicide of the past.

Responses Induced in Plants by Growth-Regulators

Plant growth-regulators are sometimes referred to as "plant hormones" or "phytohormones". Unlike animal hormones which are highly specific in character and, in general, control a limited set of transformations, the so-called plant hormones have the appearance often of being relatively unspecific and of controlling, initiating or directing a number of superficially unconnected changes.

Most growth-regulators, if applied to plants at sub-lethal or sub-inhibitory levels, may give rise first to curvatures or epinastic responses and later to so-called formative effects or changes in the general morphology or habit of growth of the plant. Terminal growth may cease and axillary bud development be induced so that a low bushy plant results; the stem may thicken and split; leaf modification may appear with

changes in shape and patterns of venation; the root system may be altered in character. It is to be noted that responses can be produced either in actively growing tissues or by reactivation in maturer tissues of cells which have already completed their normal growth. In some cases normal differentiation appears to be prevented, and gall tissue or callus tissue may be formed as a result of division and proliferation of cells without subsequent differentiation.

Present Uses of Growth-Regulators

The uses that have been made of growth-regulators to date do not fall into any single pattern. In a general way they can perhaps be put into two categories, though the responses involved are not always sharply separable. In the first category are uses that depend on some inductive or formative effect in the plant. Such applications are usually relatively critical with respect to dosage, but not necessarily specific with respect to the active compound. In the second category are treatments that are primarily inhibitory or even lethal. It is likely that many applications of both types remain to be developed.

Root Initiation. Vegetative propagation of plants has been aided greatly by the finding that root initiation can be induced in cuttings of many species by brief treatment with growth-regulating compounds. Those most widely employed for this purpose are indole-3-butyric acid and alpha-naphthaleneacetic acid or a derivative thereof. Many substituted phenoxyacetic acids have the same property, but as the margin between active root initiation and inhibitory or formative effects in other parts of the plant is much narrower in this group, they are not ordinarily employed. The rooting response is particularly useful in the case of woody and semi-woody species. Not all species, however, can be induced to root by application of compounds currently available; they thus present a challenge to the chemist and physiologist to seek additional substances with this property.

Fruit-setting and Flower Drop. By treatment of some flowers with certain growth-regulators, fruit-set without pollination may be accomplished. The fruit so obtained is seedless. Applications are usually made by aerosol or vapor treatment. Alpha-naphthaleneacetic acid or some derivative is the main choice, though the list of compounds known to induce parthenocarpic fruit development is extensive. Fruit so produced may be larger in size or weight than fruit formed as a result of normal pollination, although undesirable changes in the morphology of the fruits may be encountered if the optimum treatment rates are exceeded. The chemical treatment may also prevent flower drop and ensure fruit development from flowers which have been previously pollinated. This technique has been employed widely by growers raising tomatoes in greenhouses where pollination normally is poor, and it appears possible in this way to overcome also the adverse effects of low night temperatures on fruit setting of early field-grown tomatoes.

Bud Initiation, Inhibition and Stimulation. Certain compounds are capable of inducing development of flower buds and so permit some control of the time of flowering. This has proved successful in pineapple culture. Again, alpha-naphthaleneacetic acid has been the compound mainly employed. Curiously enough, this same compound, as well as its derivatives, is highly effective in inhibiting bud development in many other plants, and they are widely employed for preventing sprouting of potato tubers in storage. On the other

hand, chemicals are known which have a bud-stimulating influence, and these are used for forcing dormant buds, for example, in potatoes which are to be planted as seed.

Delaying and Prolonging Flowering. Considerable effort has gone into experimentation on delaying the flowering of fruit trees, such as peach and apple, in order to reduce the likelihood of late frost injury in the spring. The margin between dosages which can delay flower opening and those which induce floral abnormalities is a slim one, however, so that treatments of this type are not yet regarded as safe and have not come into general practice. Experimentation aimed at prolonging the blossoming period of decorative fruit trees also has given promising results.

Fruit Drop. Whereas rooting, fruit setting and bud forcing responses are examples of stimulative effects, the prevention of pre-harvest drop of fruits, a practice now widely favored by orchardists, involves an inhibitory action. Many varieties of apple and other fruit commonly fall from the tree before they reach the degree of ripeness desired or before they can be picked so as to avoid bruising. Suitable chemical treatments can apparently delay the development and separation of the abscission layer of cells which is responsible for fruit fall, without causing appreciable change in the rate of ripening. Alpha-naphthaleneacetic acid or a derivative is ordinarily employed at a very low concentration in dusts or sprays. 2,4-D also is effective on certain species.

Accelerating Ripening of Fruit. The normal metabolic behavior of some fruits and vegetables in storage can be altered by treatment with growth-regulators. The ripening of bananas, for example, is accelerated by exposure to a low concentration of 2,4-D, which might be preferable to ethylene as presently employed.

Weed Eradication. Excelling all other uses in importance to agriculture and to the chemical industry at this time, however, are the remarkable applications of growth-regulators in the herbicide field. The substituted phenoxyacetic acids, of which 2,4-dichlorophenoxyacetic has been most studied, can be employed broadly for weed eradication or vegetation control. Although they are not inherently selective in activity they can be utilized in a selective manner by taking advantage of differences in sensitivity and response among species. Perhaps the most important agronomic development is the control of weed growth in a planted or growing crop, either by spray treatments which inhibit weed growth selectively, or by soil teatments which prevent germination and development of weed seedlings.

Production and Consumption of Growth-Regulators

Considering that experimentation with a view toward utilizing 2,4-D as a herbicide was not initiated until 1943, production and sales of growth-regulating chemicals in the United States have shown a remarkable increase during the past few years. In 1945, the first year in which production was sufficiently large to be reported by the U. S. Tariff Commission, 917,000 lbs. of this compound were manufactured. In 1946 the amounts of 2,4-D and its derivatives had increased to 6,461,000 lbs. and in 1947 to 8,866,000 lbs. For the last quarter of 1948, production of the acid was at the rate of 27,512,000 lbs. annually. The figures for naphthaleneacetic acid in 1945, 1946 and 1947 are 33,000, 12,000 and 14,000 lbs. respectively. Thus in a period of three years plant growth-regulator production has grown to a multimillion dollar business.

No data are available as to the actual end uses of 2,4-D, but it may be

presumed that the great bulk of this material is used in weed control on cultivated or pasture land. In 1946 and 1947 sales amounted to 90 per cent of production. If this figure is carried over to 1948 and the further assumption is made that 90 per cent of this amount was applied to agricultural land at an average rate per acre of somewhat less than one pound, one obtains a rough estimate of 25 million acres treated during the year.

Only approximations can be made also for the second largest application of growth-regulators, that of preventing preharvest drop of apples and pears, which appears to account for the bulk of the naphthaleneacetic acid manufactured. In recent years some 2,4-D has been used for this purpose. From the first experimental spraying of four apple trees by the U. S. Department of Agriculture in 1939, about 100,000 acres of orchards were treated in 1945 and probably of the order of 150,000 acres in 1948. It is estimated that in the major fruit-producing areas of the western States, two-thirds of the pear and one-third of the apple trees are sprayed with growth-regulators. On the basis of a probable yield increase of 10 to 15 per cent and a cost of 10 dollars per acre for material and labor, the return from spraying in western orchards may be appoximated at 50 to 60 dollars per acre and at perhaps half as much in the East. A substantial amount of naphthaleneacetic acid is believed to be utilized also in the Hawaiian pineapple industry for control of flowering.

If one thinks of these compounds as plant hormones of extremely high physiological potency, the tonnages manufactured are truly startling. For example, a distinct formative effect can be obtained by application of 0.01 microgram of 2,4-D to a young bean plant, which is a commonly used test object. Applied in this way, two pounds of the chemical would be more than enough to produce a response in every edible-bean plant grown in the United States. Indeed if the total cropland of the United States were planted in beans, 4,000 lbs., or less than 0.02 per cent of the 1948 production of 2,4-D, would suffice to elicit visible effects in the plants. Even killing of all these young plants, which can be accomplished with ten micrograms of growth-regulator by suitable means of application, would require only about one-seventh of the total production.

Many of the most useful applications of growth-regulators in horticulture require only highly diluted solutions, and in consequence the total amount that is likely to be required as these practices are extended is not vast. Agronomic uses in the field of weed control are always likely to constitute a far greater bulk outlet. For example, should preemergence soil treatments for corn partially or totally supplant cultivation and be widely adopted, the demand for 2,4-D or related compounds would continue rapidly to increase to a figure several times the present consumption.

Selectivity and Specificity

Although, as already stated, there is little evidence to indicate that the compounds which possess growth-regulatory activity are inherently highly specific and selective in action on particular genera, species or varieties of plants, there is a high degree of probability that many can be used in a selective manner. Selectivity is often more apparent than real and is the resultant of different degrees of susceptibility to a particular concentration or amount of active compound. For example, many of the selective herbicidal uses of 2,4-D

involve only a dosage selectivity. Established monocotyledonous plants, particularly the cereals and other grasses, are little affected by top application of growth-regulators of the phenoxyacetic type, whereas many broad-leaved plants at a corresponding stage of growth may be heavily affected. However, germinating seeds and young seedlings of grasses may be highly susceptible. Although there appears to be some major difference in sensitivity between monocotyledonous and dicotyledonous species, there are exceptions and inconsistencies in responses to particular compounds. Whether there is a basic biochemical difference between responsive and unresponsive species is not known. The alternative view, namely, that absorption of these compounds and subsequent transport to young rapidly growing tissues may not be accomplished or may be accomplished only slowly by the unresponsive species, may hold in some cases.

In general, as the tissues and organs of plants age and mature they become increasingly less responsive to applications of growth-regulators, and high dosage rates at a late stage may not achieve what can be accomplished by much lower concentrations at an earlier stage. Some of the inductive or formative applications of growth-regulators exploit the different susceptibilities of tissues or organs. The cells involved in floral development, for example, are physiologically young and highly susceptible, whereas most other tissues at this stage are further advanced and, therefore, not likely to be affected by treatments that can result in profound effects in fruit or seed development. It is probable that advantage will be taken of similar differences in organ and tissue susceptibility to develop many other apparently selective uses for growth-regulators.

Structure and Activity

Information relating the molecular structure of plant growth-regulators to their physiological potency is highly desirable both for its possible value in pointing the way toward new "tailor-made" compounds and also in yielding clues concerning the mode of action of these substances. Many pitfalls, not always clearly recognized, stand in the way of obtaining such information, and despite considerable effort present knowledge is quite fragmentary.

Among the heterogeneous assemblage of compounds embraced by the generic term "plant growth-regulators" are some which are very versatile in activities, being capable of producing several of the types of responses previously outlined. Other compounds appear to possess appreciable activity in only a single physiological effect. Thus in endeavoring to relate structure with activity it is essential to define as clearly as possible the kind of activity under consideration and, in some cases, also the precise technique employed in eliciting and measuring the response.

Comparative tests on extensive series of compounds have been reported from only a few laboratories, and among these there exist numerous instances of contradictory results possibly caused by differences in methods.

Some confusion may have arisen through failure to distinguish between what may be termed "intrinsic activity" and "apparent activity". If it is assumed that growth-regulators are effective by virtue of some biochemical reaction in which they participate, then the intrinsic activity would be a measure of the effectiveness of such participation. In practice, what is actually measured is only the apparent activity, which may be the resultant of various ancillory properties such as absorbability by the plant, solubility of the com-

pound in the plant fluids or protoplasm, transportability of the substance within the plant, and rate of inactivation of the material within the plant. As evidence for this statement may be cited the fact that the magnitude and even the character of response to a particular dosage of growth-regulator may be substantially changed by altering the carrier solvent or the mode of presentation.

Additional handicaps to progress on this subject have been the lack of critical methods for evaluating various types of responses, and the difficulty of expressing certain of these responses quantitatively.

At the present stage of development it appears possible to make two, seemingly contradictory, generalizations. On the one hand, what appears to be the same, or certainly closely similar, effects can be produced by a considerable diversity of structural types of molecules. On the other hand, among isomers, analogs, homologs and derivatives of a particular type, a high degree of specificity is exerted by what may be termed loosely the "fine structure" of the molecule. In some cases, however, the structural specificity exhibited in a particular physiological effect does not appear to hold for other effects.

Relatively few aliphatic compounds have been reported to possess growth-regulatory activity, but this may be a reflection of the greater attention which has been given to cyclic compounds.

The majority of the compounds so far demonstrated to be active may be regarded as derivatives of a relatively small number of parent substances which are for the most part ring-substituted aliphatic acids.

Table I shows in a general manner the kinds of activity exhibited by certain of the better known of these classes of compounds. The ratings are intended merely to be roughly indicative, and many exceptions could be noted. Qualitative as well as quantitative differences in responses do occur and further complicate comparisons.

In the phenoxy and benzoic acid series, substantial numbers of isomers, homologs and derivatives have been investigated, so that certain tentative generalizations concerning the role of the finer structure appear permissible. Of paramount importance for growth-regulatory activity is the substitution of certain of the ring hydrogens. Many of the unsubstituted parent compounds are virtually inactive. The kind, number and position of the substituent atoms or groups all are influential, but the precise role of each seems to vary with the particular parent series.

In the phenoxy series, activity is imparted by substitution in the 4-, 2,4- and 2,4,5- positions and, to much smaller degree, in the 2-, 3- and 2,5- positions. Halogen substituents are more effective than any other. Activity increases with number of substituent halogen atoms up to two or three but falls off with further halogenation. Other substituents, such as alkyl, nitro and hydroxyl groups, may increase activity, especially if halogen substituents are present in addition.

Halogen substitution increases activity in the phenylacetic and benzoic acids also, particularly if as many as three substituent atoms are present. In the benzoic series the nitro group has a very marked activating influence, especially in mixed-substituted compounds also containing halogen. Introduction of methyl, hydroxyl or amino groups into active halogen- or halogen-nitro substituted compounds often diminishes the activity. The most favorable positions for substitution in the benzoic acids are 2, 3 and 5, in contradistinction to the phenoxy acids in which they are 2, 4 and 5.

In general, the presence of a free carboxyl group is not essential. Activity comparable with that of the acids is exhibited by many of the corresponding salts, amides and esters. Indeed, in numerous instances such derivatives seem to have appreciably greater activity than the acids themselves, a circumstance which weakens but does not negate the view that *in vivo* hydrolysis to the acid is a prerequisite to physiological action. Nitriles, thioacids, alcohols and ethers also may possess activity.

The length of the carboxyl-bearing side chain may be of great importance. Substitution of the 2,4-dichlorophenoxy radicle on the omega carbon of the straight chain aliphatic acids confers activity only on those with an even number of carbon atoms (acetic, butyric, caproic, caprylic), whereas the odd-numbered (propionic, valeric, enanthic) are relatively inactive. This appears to hold also for naphthoxy-substituted compounds but not for indole-substituted. It has been suggested that

TABLE I
SUMMARY OF ACTIVITIES OF VARIOUS GROUPS OF GROWTH-REGULATORS

	Activity						
Class of Compounds	*Stimulation of Cell Elongation*	*Stimulation of Cell Division*	*Root Initiation*	*Modification of Organs (Formative effects)*	*Parthenocarpy*	*Retardation of Abscission*	*Bud Development*
Indole-aliphatic acids	+++	++	+++	±	+		inhibition
Phenyl-aliphatic acids	+	+	+	0	±		stimulation
Naphthyl-aliphatic acids	++		+++	±	++	+++	inhibition
Benzoic acids	±	++	++	++	++		
Phenoxy-aliphatic acids	+++	+++	+++	+++	+++	+++	inhibition
Naphthoxy-aliphatic acids	++		++	+++	+++	++	
Aromatic substituted carbamates	0	inhibition (mitotic aberrations)	0				
Carbon monoxide	++		++	0	0		
Unsaturated aliphatic hydrocarbons	+++		+++	0	0	−	stimulation

+++ high activity
++ moderate activity
+ slight activity
± very slight or doubtful activity
0 inactive
− acceleration of abscission

the higher-membered even carbon acids may be degraded *in vivo* by successive beta-oxidations to the active phenoxyacetic acid, which could not be formed in this way from the odd-numbered acids.

Where substitution of the aromatic residue is on the alpha carbon, the propionic and butyric acids frequently are more active than the lower or higher homologs, or than various dicarboxylic acids.

The indole compounds occupy a somewhat special position among growth-regulators inasmuch as the only naturally occurring plant hormone, the existence and identity of which is beyond question, is heteroauxin or indole-3-acetic acid. Indoleacetic acid appears to be widely distributed in plants, and it seems to be tacitly assumed, if not dogmatically claimed, that it is the central "growth-regulator" common to all chlorophyllous plants. An enzyme capable of oxidizing indoleacetic acid to an inactive product has been demonstrated in some plants. Such enzymic destruction might account for the lower apparent activity exhibited by indoleacetic acid in some responses in comparison with "foreign" compounds, with which the plant is less well able to cope. Halogenated or otherwise substituted indole acids have received only scant attention, although active compounds might logically be sought among them.

A quite different aspect of the relationship between structure and biological properties of the compound may also have to be taken into account. Employment of weed control methods involving soil applications rather than top treatments will call for compounds not readily decomposed or inactivated by the soil microflora and, therefore, capable of persisting in the soil and preventing development of weeds in the crop for a whole season. From this standpoint 2,4,5-trichlorophenoxyacetic acid would be preferable to 2,4-D, for example, in the pre-emergence weed control treatment of corn.

Mechanism of Action

Many of the responses which have been described for plant growth-regulators appear to depend ultimately upon alterations in the rate or direction of cell enlargement or of cell division. In addition, various biochemical processes involved in metabolism of carbohydrates and nitrogenous substances may be influenced, either with or without detectable morphological changes. While the causal relationship between the biochemical and structural responses is not clear at the moment, it may be presumed that the more complex morphological effects are initiated by chemical processes.

It is uncertain, too, whether or not diverse growth-regulatory compounds act fundamentally in a similar manner, that is, whether there is a common controlling mechanism which can lead to various end results. A satisfactory explanation must reconcile the following observations: (*a*) a variety of compounds may produce the same end result; (*b*) a single compound may bring about several apparently unconnected responses; (*c*) two compounds may behave entirely similarly with respect to one physiological effect but disparately in some other response; (*d*) even though the same general response, such as root initiation or cell elongation, may be brought about by different compounds, there may be found more or less marked qualitative differences in the character of the response; (*e*) plants classified in the same family or genus and which presumably have strong biochemical affinities may not respond in the same manner to particular growth-regulators.

One current view is that exogenous growth-regulators act by influencing, accelerating or blocking the biochemical processes controlled by indoleacetic acid or other cellular growth-regulators. However, understanding of the physiological role of the endogenous hormones is still so incomplete that it is not possible yet to formulate any common mechanism of action. There is some evidence indicating that the exogenous growth-regulators may be effective only at a particular stage in the development of cells and tissues and that the morphological and formative changes that result from treatments are limited to cells at this stage during the time when the chemical is applied.

Certain compounds, such as the phenylcarbamates, cause great cytological aberrations; other major groups, such as the phenoxy- and naphthoxy- compounds, bring about marked histological changes without apparent cytological disturbances.

Because of the diversity of chemical structure of active growth-regulators, some investigators have inclined to the view that their common characteristic might be some physical property and that their activity might be of a physico-chemical nature, such as an influence on permeability.

Future Agricultural Uses

Up to the present the main agricultural outlet for growth-regulatory chemicals has been for weed control and weed eradication. The current pre-occupation with 2,4-dichlorophenoxyacetic acid for these purposes is hardly likely to be maintained. 2,4-D is a broadly effective and highly inhibitory compound; others that are safer to use or better suited for particular purposes are already known, and it may be confidently predicted that still others remain to be discovered.

Developments in weed control conceivably could result in far-reaching changes in cultural practices. Some rotations and many agricultural operations have been adopted primarily for purposes of weed control. A greater measure of chemical control of weed competition in the growing crop would surely allow more intensive cropping and, therefore, require greater attention to be given to the nutrient status of the soil. The per acre yield of corn can probably be appreciably increased if the old 42″ check row spacing is abandoned. Developments in the selective use of growth-regulators for weed control may well result, therefore, in greater demand for fertilizers in order to support more intensive land use.

Considered from the standpoint of the crop, the present herbicidal uses of growth-regulators are all indirect. The underlying principle is the prevention or removal of weed competition. The future holds great possibilities for direct uses involving application to the growing crop for purposes of crop growth-control. Most of the presently developed specialized horticultural uses, which involve rooting, flowering or fruiting, fall into this category. The common field crops that bulk large in producing the food and fiber of the world may be as susceptible to control as are those horticultural and fruit crops that have hitherto received more attention. Moreover, other uses, for which there are as yet no precedents, will likely follow.

The situation now confronting the agronomist and horticulturist is that some of the characteristics of plants previously accepted as fixed are in fact not immutable, and that agricultural and horticultural systems and practices developed on such assumptions may undergo great change. One of the goals of scientific agriculture in the past has

been to secure for every locality plants fully adapted to that environment, and capable, therefore, of making maximum yields under the prevailing climatic and edaphic conditions. A long-season plant may not mature in northerly latitudes; a plant requiring high night temperatures may not be fruitful if the temperatures are low. It is highly probable that some of the factors governing plant adaptation will be susceptible to control or circumvention by growth-regulators. This may result in higher yields or a greater certainty of yield. Furthermore, it may result also in some change in crop distribution. Flowering time, flower abundance, fruit and seed setting, and maturity date may be susceptible of control. In a late season, flowering of some plants might be advanced in order to obtain maturity before the frosts of autumn. In an early spring, bud development and flower opening in fruit crops might be delayed to obviate late frost injury. Parthenocarpic fruit setting may be widely practiced with the result that seedless or almost seedless fruits and vegetables become common; the dependence upon insects and other natural pollinating agencies may be reduced and so provide greater latitude in the use of insecticides.

Visible changes in the morphology or yield of the fruit or grain, or other edible part of any crop, may be accompanied by changes in chemical composition. As yet this aspect has been little studied. The indications are that the balance between reserve carbohydrates and simple sugars may frequently be changed as the ripening process is delayed or accelerated by growth-regulators. There are reports that grain from wheat treated with 2,4-D for weed control may have a higher protein content, and that parthenocarpic tomatoes are sweeter than those produced by pollination. Information along these lines is very scanty; although not all such changes may be desirable, there is basis for the prediction that some measure of control of composition and, therefore, of quality is likely to be achieved.

The combination of crop control and composition control might be of outstanding importance with certain grasses and forage crops. The digestibility, palatability and feeding value of pastures decline rapidly as the dominant grasses head and mature. Delayed heading, or inhibited heading, with a resultant permanently vegetative leafy plant, might greatly change the quality of pastures and permit more intensive use of grazing land and meadows in the humid regions.

Research in the general fields of weed control and crop control is at present proceeding largely in an empirical manner. Interest is centered on 2,4-D and naphthaleneacetic acid or their derivatives. One of the main factors at present retarding the development of new growth-regulators and additional uses for such substances is the lack of fundamental knowledge as to the mechanism of action of this class of compounds. The horizons of the future are not yet clearly discernible. The potentialities and limitations cannot, therefore, be sharply outlined, but it is certain that agricultural practice may be greatly changed in form and direction by the availability of these new chemical tools.

Forest-Tree Genetics Research: *Populus* L.

The genus Populus, because of its considerable economic importance coupled with favorable experimental characteristics, has attracted the interest of many investigators of tree genetics and may truly be called the "guinea pig" of forest-tree breeding.

SCOTT S. PAULEY
Harvard Forest, Petersham, Massachusetts

Introduction

With the possible exception of the pines, no forest tree genus of the northern hemisphere has received so much attention from forest geneticists and tree breeders as has *Populus*. The results of these studies have been published in numerous widely scattered journals and bulletins, some of which have very limited circulation and availability. This review represents an effort to assemble the available data, but no claim for completeness is made.

At least two valuable reviews have appeared in recent years which discuss forest genetics research in *Populus*, but both have limitations. Richens (204) reviewed the entire field of forest tree breeding and genetics research since 1930, and Farrar's review (83) is limited to an account of the work in Canada.

The poplars are, in general, characterized by rapid growth rates, ease of propagation by twig or root cuttings, and winter hardiness. All are wind-pollinated, essentially dioecious[1], hybridize readily within and between most sections of the genus, and are capable of successfully maturing immediately viable seed on cut twigs in the greenhouse. In the Baltic regions and in central Europe intensive mangement of various species and hybrid clones has been practiced for many years. In North American forestry most poplar species have only recently evolved from the "weed" category, and in consequence an increasing interest in this group is being demonstrated by Canadian and American foresters. With these generally attractive biological characters and sympathetic economic circumstances prevailing, it is not remarkable that considerable interest has been directed to this genus by forest geneticists and tree breeders in this part of the world and abroad.

Classification and Nomenclature

Populus is represented by about 30 tree species which, except for one species[2], are confined to the temperate regions of the northern hemisphere. The genus is divided into five sections: (*a*) *Leuce* Duby (white poplars, aspens); (*b*) *Leucoides* Spach; (*c*) *Tacamahaca* Spach (balsam poplars); (*d*) *Aegeiros* Duby (cottonwoods, black poplars); and (*e*) *Turanga* Bunge (201). The geographical ranges of these natural divisions, as indicated by their principal species, are shown in Table 1 wherein

[1] Hastings (102), Erlanson and Herman (82), Aljbensky (3), Peto (193) and, doubtless, others have reported some members of the genus as showing a monoecious or polygamo-monoecious habit. East (80) believed the occasional perfect flowers to be self-fertile.

[2] *P. Denhardtiorum* (Engler) Dode, native of equatorial east Africa (78).

the classification, nomenclature and ranges follow essentially those of Rehder (201).

It will be noted that only one section (*Leuce*) is represented in the three principle regions where poplars are found and that Europe has only three native species in two sections (*Leuce* and *Aegeiros*). These three species, however, with some of their numerous named varieties and hybrids are all of considerable importance in European forestry practice.

The 12 species indigenous to North America represent four sections, but only four or five of the species (*tremuloides, grandidentata, tacamahaca, trichocarpa* and *deltoides*) occur at present in sufficient quantity to be of commercial importance.

Considerable taxonomic difficulty prevails in the genus with regard to the proper nomenclature to be used for certain species, varieties, forms or hybrids of the several polymorphic and easily hybridized species. A number of workers have striven to bring some measure of order out of the chaos. In Great Britain Elwes and Henry (81), Henry (109, 111, 114) and Cansdale (55) have contributed to taxonomic clarification of the especially difficult and confused section *Aegeiros*. Houtzagers (116, 119) in Holland; Dode (77), Régnier (198, 199), Guinier (99), Meunier *et al* (172) in France; Gomboez (92) in Hungary; and Sargent (210, 211) and Rehder (201) in the United States have also provided revisions and revaluations in

TABLE I

Populus: Geographical Range by Principal Species

Section	*North America*	*Europe and Western Asia*	*Central or Eastern Asia*
Leuce	*P. grandidentata* Michx. *P. tremuloides* Michx. *P. Brandegeei* Schneid.[3]	*P. alba* L. *P. tremula* L.	*P. alba* L. *P. tremula* L. *P. Sieboldii* Miq. *P. adenopoda* Maxim.
Leucoides	*P. heterophylla* L.		*P. lasiocarpa* Oliv. *P. Wilsonii* Schneid.
Tacamahaca	*P. angustifolia* James *P. acuminata* Rydb. *P. trichocarpa* Hook. *P. tacamahaca* Mill. (= *P. balsamifera* L.?)[4]		*P. Simonii* Carr. *P. yunnanensis* Dode *P. szechuanica* Schneid. *P. tristis* Fisch. *P. cathayana* Rehd. *P. Maximowiczii* Henry *P. koreana* Rehd. *P. laurifolia* Ledeb.
Aegeiros	*P. deltoides* Marsh. *P. Sargentii* Dode *P. Wislizeni* (S. Wats.) Sarg. *P. angulata* Ait.	*P. nigra* L.	
Turanga		*P. euphratica* Oliv. (No. Africa to central Asia) *P. Denhardtiorum* (Engler) Dode (Tropical east Africa)	

[3] = *P. monticola* Brandegee. This imperfectly known species (47), endemic of southern Lower California and Sonora, is believed by Sargent (209, 210) and others to represent the New World counterpart of *P. alba* which it closely resembles.

[4] *P. balsamifera* L. is considered to be a *nomen ambiguum* by some authors; not so by others (116, 207).

nomenclature for various sections of the genus. Stout (236) and Stout and Schreiner (239) have emphasized the taxonomic confusion introduced by the early practice of assigning Latin binomials to natural or artificial F_1 hybrids which have been propagated vegetatively as clones. A further element of confusion is provided when, as in the case of the artificial hybrid X *P. generosa* Henry, it is found that not one but several sibs of both sexes, all vegetatively propagated, masquerade under the same name. The genetic ambiguity surrounding the binomial X *P. generosa* is, however, a comparatively ephemeral mist, not to be confused with the special degree of genetic confusion associated with such natural native hybrid names as X *P. Jackii* Sarg. (= *tacamahaca* × *deltoides*) and X *P. Andrewsii* Sarg. (= *Sargentii* × *acuminata*), each one of which is used to designate an entire hybrid swarm occurring in regions of range overlap of the parent species. Such mass grouping appears to be a legal and probably justifiable expedient on taxonomic grounds, but from the standpoint of genetic studies it is obviously unsatisfactory.

Forest genetic literature relating to the poplars is, as a result, especially rich in taxonomic confusion. Workers with such genetically obscure material have an understandable reluctance to assign authority names to the scientific names used, and it is therefore often difficult even to identify the section to which a plant name in question actually belongs. But even such apparently satisfactory names as "*P. canadensis* Moench", complete with authority, may be quite meaningless. Due to the ambiguity contained in the original description made by Moench, the name has been attributed to at least five species and three hybrids in two sections by various taxonomists (55).

The determined attitude of poplar specialists in Europe to establish a practical working basis for taxonomic problems is reflected in the activities of the Commission International du Peuplier (21). Through a careful tabulation of the numerous clonal lines of poplars, especially of the section *Aegeiros,* cultivated in Europe, and with due regard to the International Rules of Botanical Nomenclature, this body proposes to secure a functional standardization in nomenclature to replace the present prevailing inextricable confusion.

A step in the right direction in this country was the precedent established by Schreiner and Stout (227) when they assigned clonal names, such as "Frye" and "Rumford", to ten of their selected hybrid clones. It is becoming increasingly apparent that individual names or numbers for such vegetatively propagated individuals, regardless of their taxonomic status as "species", "varieties", "forms", "hybrids", *etc.*, must be adopted by forest geneticists and breeders if any semblance of order is to be established in the genetic nomenclature.

Utilization

The wood of the American and European species and varieties of poplar is employed in considerable quantities for pulp, match-sticks and boxes, excelsior, veneer, small dimension lumber for interior trim, boxes, crates, wooden shoes and numerous other small articles of woodenware (52, 196, 120). Of peculiar interest is the fact that the natives of Kenya Colony, Africa, use the native *P. Denhardtiorum* in the manufacture of their dugout canoes (34).

Although long used and of respected industrial position in Europe and South America (Chile and Argentina) (196), poplar wood in this country has slowly

gained in popularity for more general use only during the past decade. This increasing popularity, however, has probably been due to the demands of necessity resulting from the gradual elimination from the trade of various preferred species rather than to any fundamental change in relative value concepts.

The awakening interest in the use of poplar wood in the United States is best demonstrated by the stimulated activity in utilization research designed to find new uses and improve old processing techniques for trembling and largetooth aspen (*P. tremuloides* and *P. grandidentata*) in the Lake States. Due to poor cutting methods and lack of fire control, the original pine lands in this area were converted to almost pure stands of aspen early in this century (88). In the combined forested areas of Michigan, Wisconsin and Minnesota, aspen today is said to be of primary importance on some 20 million acres, representing 40 percent of the commercial forest land area (70).

In 1947, through the active interest of the United States Forest Service's Lake States Forest Experiment Station, a series of 21 reports on the aspen situation in that area were undertaken by members of this organization and other cooperating agencies. Most of these reports are now available (56, 62, 65, 89, 137, 146, 197, 205, 208, 213, 215, 232, 241, 250, 258, 293, 294, 297). Twenty of the bulletins are concerned with the technicalities of utilization and exploitation of this newly discovered wealth, but at least one (297) is devoted to summarizing the limited silvicultural data on aspen which have accumulated in this country.

Selection from Wild Stock

It is generally accepted by plant breeders that an initial step in a breeding program should involve a careful evaluation and selection of breeding stock from the wild type. Although conceded and recommended by tree breeders in this country (221, 231, *etc.*), there is no published evidence to indicate that such studies have been undertaken with the native poplars.[5]

In the United States the various wild species, forms and hybrids of *Populus*, both native and exotic, were claimed by Stout and Schreiner (239) to be incapable of fully satisfying the demands for direct use in reforestation projects. In spite of this observation a search for superior wild individuals to be used either directly as clones or as parental stocks for progeny tests and hybridization studies appears logical and justified. In view of the wide range of climates occupied by many of the North American poplars, it might be anticipated on the basis of Turesson's (261, 262) conclusions and those of Clausen, Keck and Hiesey (57, 58, 59) that a probable wide range of genetic variability exists in the wild populations of our native species.

Contrary to the complacency exhibited in this regard in this country, considerable effort has been directed in Europe to the selection of natural hybrids, varieties and élite forms of poplars for direct use in forest plantations or as parental stock in simultaneously conducted progeny tests and breeding programs.

In France, Belgium and Holland, where the black poplars are grown under intensive management for veneer, match stock and small dimension lum-

[5] Tests of wild élite forms of native poplars are, however, currently under investigation at the Mayo Forestry and Horticultural Institute, Rochester, Minnesota, in collaboration with the Forestry Department of the University of Minnesota; at the Department of Pathology, University of Wisconsin, Madison, Wisconsin; and at the Cabot Foundation for Botanical Research, Harvard University, Harvard Forest, Petersham, Massachusetts.

ber, the majority of cultivated clones have been selected from natural variants of the native black poplar (*P. nigra* L.), introduced forms of *P. deltoides* Marsh., *P. angulata* Ait. and chance hybrids which have occurred between them since introduction of the American forms in the latter part of the 18th century.

These "Hybrides Euraméricains" include the so-called "Régénéré de l'Ourcq", a clone of the cross *deltoides* × *nigra* and variously referred to in the literature as X *P. regenerata* Henry or X *P. canadensis regenerata* ((Schneid.) Rehd. var.). This clone, although susceptible to canker, is much prized for its rapid growth rate and good wood quality and is said to be the most important in France in number of trees and surface occupied. Other important clones are the "Vieux noir"; "Suisse", or "Black Italian Poplar" (X *P. serotina* Hartig = X *P. canadensis serotina* (Hartig) Rehd.); and still others of the same hybrid origin called "Blanc de Poitou" and "Raverdeau blanc". The clone of an *angulata* × *nigra plantierensis* cross (X *P. robusta* Schneid.) is of importance in the production of match stock. This is a rare case of specificity in the naming of clones, for it is believed that only one seedling of the cross was propagated (55).

In addition to the above, clones of the following are currently planted to a considerable extent in Holland: X *P. gelrica* Houts. (= X *P. serotina* × X *P. marilandica*); X *P. serotina* Hartig var. *erecta* Henry; X *P. marilandica* Bosc.; X *P. berolinensis* Dippel (= *P. laurifolia* × *P. nigra* var. *italica*); and X *P. regenerata* Henry var. *erecta* Houtz. (116, 119, 120). For further data on the clonal lines propagated in western Europe, the following references may be consulted: 1, 21, 31, 32, 107, 152, 172, 198, 237.

Interest in the use of poplars for forestry purposes has been manifest in England in recent years. Henry (112), Lotbinière (166, 167) and Ackers (1) believe the growing of poplars under forest management to be economically sound, provided desirable stock and suitable sites are utilized. This has encouraged search for the most desirable wild forms best suited to the plan of management and utilization. A valuable initial step in this direction was accomplished by Cansdale (55) in his "The species and hybrids of *Populus* cultivated in Britain". An accumulation of other supplementary evaluating information on individual members of the genus has also been made by the same author.

Cansdale and Ackers believe that X *P. regenerata* Henry and another clone of the same hybrid origin (*P. regenerata* Henry var. *erecta* Houtz.) may well prove to be valuable timber producers in the British Isles as they have in France. These clones have been grown successfully in forest plantations in England for a full rotation (40–60 years) in several localities with high yield.

According to Ackers, other native clones or introductions, including most of the black poplar varieties or hybrids grown on the continent, are promising for forestry use. The species *P. yunnanensis* Dode, a balsam poplar of China, and *P. trichocarpa* Hooker of the Pacific coast region of North America are being tested in forest plantations on various sites in the British Isles.

Interest in wild selection of poplars in Germany is chiefly reported in the work of Wettstein (271, 278, 279, 280, 282, 283, 285). This investigator (276) indicated that studies of climatic races in various species of *Populus* and other genera have been carried on by the German Association for the Breeding of Forest Trees.[6] Isolation of at least two climatic strains of *P. tremula* L. was

[6] Established through the interest of Erwin Baur in 1932.

later reported by Wettstein (278), and reports of progeny studies, showing variation among the seedlings of *P. tremuloides* Michaux and *P. tremula*, were made by the same author (280).

Vill (264) reported that the hybrid X *P. charkowiensis* Schröder [possibly X *P. canadensis Eugenei* (Simon-Louis) Schelle, the "Carolina Poplar", commonly planted as a street tree] is being grown extensively in the Rhineland. Although the clone under plantation conditions is said to make very good growth and to show considerable promise as a timber producer, it is, nevertheless, subject to canker.

In Sweden the Swedish Forest Tree Breeding Institute (Ekebo, Källstorp, Sweden) has directed considerable of its effort to the isolation of superior wild forms of *P. tremula* as a normal initial step in its aspen-breeding program (144). Selected trees must conform to high standards of stem form, branching habit, health and vigor before being acceptable for progeny tests and breeding studies. The discovery of nine clones of natural triploid *P. tremula* (42, 180, 138, 257), resulting from such surveys of wild stands, gives promise of supplying valuable wild material for direct forestry use and further breeding. According to Nilsson-Ehle (180, 182), the first triploid clone which was discovered in south Sweden grows more rapidly, produces more wood per year and is believed to be more resistant to attack by *Polyporus* sp. than the normal diploid form. Also, because of its "stronger growth", it is reported as able to succeed in competition with lime, maple, elm and other hardwoods. The native diploid, on the other hand, is said to be found only on the outer margin of such mixed hardwood stands in southern Sweden. Tests of the triploid, or "gigas" form, have revealed its value for use in the match and paper pulp industries. The form is reputedly easy to reproduce by root cuttings, and, since diploid × triploid crosses have been successful in producing a number of tetraploid forms (246), it has now been possible to produce triploid seed at will by diploid × tetraploid crosses (142, 143).

Jablokov (125) in Russia has also reported discovery of a giant form of *P. tremula* which appears to be endowed with the same generally favorable characters as the Swedish form. Under the currently unfavorable position enjoyed by classical genetics in that country (212), the discoverer of the Russian form was inclined to attribute its origin to "vegetative propagation", though polyploidy was not excluded as an alternative.

Controlled Hybridization and Selection

Since 1912, when Henry (110, 111) synthesized X *P. generosa* Henry by the intersectional cross *P. trichocarpa* Hooker × *P. angulata* Ait., a large number of crosses within the genus *Populus* have been effected by various workers.

Johnson (130) compiled a list of 121 natural and artificial crosses in the genus in 1939. This list was later revised by Smith and Nichols (231) who omitted crosses involving parents of doubtful identity, thus reducing the number to 93. Smith (230) provided another revision, resulting in a total of 83 crosses. A tabulation of the parents of these crosses by section were made by the same author; the resulting data are recorded in Table II.

For further summaries or original reports of inter- and intraspecific, double, or back-crosses in the genus, the following may be consulted: Schneider (217), Wettstein (273, 274, 275, 278, 284), Aljbensky (4, 5), Stout and Schreiner (239), Cansdale (55), Heimburger (103, 104), Johnson (130), Johnson and

Heimburger (136), Svoboda (243) and Richens (204).

Most workers have placed particular emphasis on interspecific crosses within the sections *Leuce*, *Tacamahaca* and *Aegeiros*, and between the latter two sections. In these combinations there is apparently unlimited compatibiilty. A few intersectional crosses involving species of *Leuce* × *Tacamahaca* and *Aegeiros* have been made. One intersectional cross (*P. lasiocarpa* × *P. nigra*) involving the sections *Leucoides* and *Aegeiros* is recorded (204), but no other record of crosses involving *Leucoides* and none for *Turanga* has come to the author's attention. On the basis of the degree of compatibility demonstrated in the other sections of the genus, it would seem unlikely to be absent in these.

Hybridizing Technique. Early hybridization studies in *Populus* were carried out through the laborious method of bagging mother trees *in situ* (238, 239), but with rediscovery of the "greenhouse methods", poplar hybridization has become amenable to modern mass production methods. Yanchevsky's (292) cut twig method, first used for hybridizing *Salix* species, in which flower bud-bearing branches of the intended parents are cut and conveniently placed in jars of water on the greenhouse bench and forced at will, was rediscovered by Wettstein (271) and successfully applied by this worker and others (140, 231, 133, *etc.*) to the poplars. A further elaboration of this technique was supplied by rediscovery of the ancient "bottle-grafting" method (41, 128, 129, 160, 290) which not only assures a greater degree of success with species that quickly mature their fruits (*Populus* and *Salix*) but makes greenhouse hybridization possible with other genera as well. By this method, branches bearing female flower buds are placed in jars of water on the greenhouse bench and are then united, in the manner of an approach graft, with the stem of a seedling of the same species growing in a pot. When the union is effected the lower portion of the branch (scion) is removed from the bottle of water and pruned off close to the point of union. It is claimed that such "dwarf trees" may continue to produce flowers and mature fruits periodically for several years.

TABLE II

NATURAL AND ARTIFICIAL POPLAR HYBRIDS WITHIN AND BETWEEN SECTIONS

Leuce X *Leuce*	*Leuce* X *Tacamahaca*	*Leuce* X *Aegeiros*	*Tacamahaca* X *Tacamahaca*	*Tacamahaca* X *Aegeiros*	*Aegeiros* X *Aegeiros*
14	2	4	7	28	28

A somewhat similar technique is suggested by current studies of bud and rootstock compatibility being conducted by the present author (187). Willow flower buds budded on a poplar hybrid rootstock in August, 1946, opened and developed with apparent normality in the spring of 1947. It is thus suggested that flower buds of desired parents might be budded on the same or different potted rootstocks and hybridized in the greenhouse. In this connection it would be of interest to determine whether the isolating mechanism of different flowering times effective between two species of overlapping range in nature might be altered by budding both on the rootstock of another species.

By use of the greenhouse hybridization methods the early practice of selecting mother trees on the basis of their

ease of access in arboreta or on boulevards rather than on the basis of more pertinent genetic characters has been essentially overcome. Twig material bearing flower buds may now be collected in the dormant condition from élite trees any place in the world where air transport is available and shipped to any other point for crossing under greenhouse conditions. The crossing of an individually superior European aspen, for instance, selected in Sweden, with an individually superior Chinese aspen from central China may now be accomplished with a minimum of effort and expense in a greenhouse in the United States.

United States. With the exception of the early tree hybridization experiments of Klotzsch, Ness and Henry, and the chestnut breeding work of Van Fleet and Graves, the first formally designated tree-breeding project was that started in the genus *Populus* in 1924 by the Oxford Paper Company, Rumford, Maine, in collaboration with the New York Botanical Garden. This work was conducted and reported by Stout, McKee and Schreiner (238), Stout and Schreiner (239, 240) and Schreiner and Stout (227).

The preliminary objective of the program was to evaluate and test the known species and hybrids of *Populus* on the basis of their value for pulpwood reforestation and to produce through hybridization more valuable types than those in existence. As previously pointed out, however, there are no available data to indicate that the evaluating and testing of the known species and hybrids were actually carried out. There is, on the contrary, abundant evidence that the hybridization program was prosecuted with vigor. About 13,000 hybrid seedlings were obtained from about 100 successful cross combinations. Thirty-four different poplars were involved as parents: three white poplars and five aspens (Sec. *Leuce*); 17 black poplars or cottonwoods (Sec. *Aegeiros*); and nine balsam poplars (Sec. *Tacamahaca*). The sections *Leucoides* and *Turanga* were not involved. A detailed list of individual crosses has not been incorporated in this review but they are available in the original papers by the authors noted above and in the list of hybrids compiled by Johnson (130).

Initial selection of the hybrid population, based primarily on vigor of growth, was made during the second year. Six hundred seedlings were thus selected. The remainder, and also those weeded out by subsequent selections, were planted in a forestation plantation. Cuttings of the selected plants were also thus planted. Significantly, some of the earlier discarded plants were later selected on the basis of their performance in the forestation planting.

The second selection reduced the number of selected clones to 69. All of these were hybrids within or between the sections *Aegeiros* and *Tacamahaca*. In most cases two or more sister hybrids were represented among the 69 selected individuals. From the cross *P. nigra* × *P. laurifolia* a total of 377 hybrid seedlings were grown, and of this number ten were among the 69 selected plants.

Schreiner and Stout (195) described their finally selected hybrids on the basis of vigor of growth, ability to root from stem cuttings, hardiness and resistance to disease. Since the descriptions were based on nursery stock and young trees, it was impossible to record the sex, form of tree, and character of the trunk. Ten of the clones were assigned horticultural names, as indicated in Table III.

A number of the selected clones from these crosses have been given wide distribution for testing under various soil and climatic conditions in this country

and in Europe, but no very extensive results of these trials have as yet been published.

A point of peculiar interest to tree breeders and forest geneticists is the fact that for some obscure reason certain of the hybrids produced in this hybridization study were patented in this country and also, reportedly, in Sweden by R. H. McKee, one of the authors of the first preliminary report (238).

servations reported by Paul (185) in the case of other diffuse porous hardwoods grown under extremely adverse conditions. The resultant narrow rings contain abnormally large percentages of porous tissue with corresponding decrease in specific gravity and hardness of wood.

Johnson's (132) results from studies of the relation of growth rate to wood quality in hybrids involving *P. alba, P. grandidentata* and *P. tremuloides* are of interest in this connection. This investigator found that, although fiber length in individual fast and slow growth annual rings from the same tree showed a marked tendency for fast growth rings to produce longer fibers, data from individual fast grown and slow grown trees did not show significant relation between fiber length and growth rate. In general he concluded that nothing was found that would support a contention that abnormally rapid growth is seriously detrimental to wood quality, and that breeding work designed to produce rapidly growing forest trees can proceed with some assurance that rapid growth and good wood quality are not incompatible.

TABLE III

LIST OF SELECTED HYBRIDS SHOWING CLONAL NAME AND NOMENCLATURE OF PARENTS, ACCORDING TO SCHREINER AND STOUT (227). AVERAGE DIAMETER AND HEIGHT AFTER SEVEN SEASONS OF GROWTH FROM STEM CUTTINGS AT MONT ALTO ARBORETUM, PENNSYLVANIA, ON WELL-DRAINED SANDY LOAM (13).[7]

Clonal Name	*Parentage*	*Average DBH (inches)*	*Average Ht. (feet)*
Frye	*P. nigra* × *P. laurifolia**	6.7	37.0
Rumford	*P. nigra* × *P. laurifolia**	3.2	27.0
Strathglass	*P. nigra* × *P. laurifolia**	3.0	24.0
Roxbury	*P. nigra* × *P. trichocarpa**	2.9	26.5
Andover	*P. nigra betulifolia* × *P. trichocarpa**	1.7	17.0
Geneva	*P. Maximowiczii** × X*P. berolinensis**	3.6	29.0
Oxford	*P. Maximowiczii** × X*P. berolinensis**	2.9	27.0
Rochester	*P. Maximowiczii** × *P. nigra plantierensis*	4.3	31.5
Androscoggin	*P. Maximowiczii** × *P. trichocarpa**	3.1	25.0
Maine	*P. candicans** × X*P. berolinensis**	2.1	17.5

* = of the Sec. *Tacamahaca*; all others of the Sec. *Aegeiros*.

Schreiner (220) reported that fiber length and density of wood of the finally selected hybrids had been preliminarily investigated. On the basis of average fiber length of one-year-old wood of the hybrids (0.8 – 0.85 mm.) as compared with fiber length in one-year-old wood of *P. tremuloides* (0.53 – 0.57 mm.), the hybrids appear to be definitely superior. It was also noted that wood of the hybrids was somewhat denser than wild aspen wood grown in western Maine. This is believed to have been due primarily to the proportionately larger vessel volume, *i.e.*, greater per cent of air space per unit volume, in wood of the slower growing aspen. Schreiner's conclusions on density concur with the ob-

[7] See also Gruschow (97) and Silen (228).

Bray and Paul (48) compared the pulping quality of trembling aspen with various hybrid poplars and observed that the growth rate of the hybrids was greater and the pulp strength higher. The pulp yields per unit weight of wood of the hybrids were, however, lower and their bleaching requirements greater. Interpretation of data in this study was confounded by a variability in quality which was noted along the stem of individual trees.

The hybridization and selection work with the poplars carried on at Harvard University through support of the Maria Moors Cabot Foundation for Botanical Research is as yet incompletely reported in the literature. A number of early interspecific crosses involving species of the sections *Leuce, Tacamahaca* and *Aegeiros* were reported by Smith and Nichols (231). These workers observed that crosses involving *P. maximowiczii* appeared to be most promising.

Subsequently, double-crosses of a clone of X *P. generosa* Henry with clones of X *P. Jackii* Sarg., X *P. berolinensis* Dipp. and X *P. robusta* Schneid. have provided progenies which are now established in permanent test plantations. Interest in this material is directed especially to an analysis of the correlation existing between the juvenile and adult expression of such characters as heterosis, stem form, branching habit and disease resistance as a means of determining the accuracy with which early selections may be made in hybrid poplar progenies. A report (186) by the author based on data accumulated during the first three years of observation of the *generosa* × *Jackii* progeny indicates that selection for heterosis during the first or second year of age is not entirely effective.

Other current poplar investigations under sponsorship of the Cabot Foundation are chiefly concerned with the study of ecotypic variability within the North American species of the genus. On the basis of preliminary observations it may be stated that intraspecific crosses involving élite parents of widely separated geographic origin hold considerable promise as sources of vigorous and otherwise desirable forms.

Germany. Hybridization studies in the genus *Populus* have been reported periodically by Wettstein (271, 273, 274, *etc.*) in Germany. Of a large number of intra- and intersectional crosses made, progeny of the following were reported as showing exceptional heterosis when compared to parental vigor:

P. alba × *P. tremula*
P. alba × *P. canadensis*
P. eucalyptus × *P. canadensis*
P. alba × *P. nigra pyramidalis*
P. tremuloides × *P. tremula*

Intraspecific crosses involving climatic strains of *P. tremula* were reported by Wettstein (278, 279, 285), and in most instances hybrid vigor of the progenies, based on the first season's height growth, was well marked.

The breeding work of Wettstein has not been directed primarily to the synthesis of rapidly growing forms but to the development of new forms less exacting in their site requirements. Poplar culture in Europe has so developed that the species *P. alba* and *P. tremula* have been almost entirely eliminated because of their slow growth, crooked stem form and normally small dimensions on poor soils in western Europe. In utilizing these species as parents, Wettstein has hoped to obtain hybrids showing heterosis and improved form but still making low site demands.

Wettstein's studies of ecotypic variability (250) demonstrated that ecotypes of *P. tremula* found in continental or cold regions have greater frost resistance and a shorter growing season with ear-

lier entrance into dormancy than types of milder climates. Swedish and East Prussian *tremula* trees, for instance, when grown near Berlin, begin their dormancy in September, whereas *tremula* of western or southern provenance is still green in October.

In intraspecific crosses of *tremula*, involving various ecotypes, length of growing season of individual hybrids demonstrated noticeable variation from that of their parents. It is thus possible to synthesize forms best suited to a particular locality.

Canada. Heimburger (103, 104) in Canada has carried on rather extensive breeding studies in the genus *Populus*. This work has been reviewed recently by Farrar (83), and a summary of crosses undertaken is tabulated by Johnson and Heimburger (136). The object of the breeding program was to produce hardy and disease-resistant material of vigorous growth for the production of wood of high quality to meet the demands of the match, veneer and pulp industries of Canada. In addition some attention was directed to the development of material suitable for shelterbelt plantings in the prairie provinces.

In 1936 Heimburger reported the successful crossing of *P. alba* L. and *P. canescens* Sm. (considered by Heimburger, Wettstein and others to be of hybrid origin: *alba* × *tremula*) with *P. tremuloides* Michx. and *P. grandidentata* Michx. The cross *tremuloides* × *grandidentata* was also consummated.

Progeny of *alba* × *grandidentata*[8] and *tremuloides* × *grandidentata*[8] uniformly displayed characters intermediate between the two parents involved. Progeny of *canescens* × *grandidentata*, however, showed great variation in vegetative characters, thus providing further evidence of the presumed hybrid origin of *P. canescens*.

Heimburger later (104) reported tests of sprouting ability of root cuttings and hardiness of the above hybrids. At the end of the first growing season root cuttings were made of the hybrids and planted immediately in the nursery where they were allowed to over-winter. All of the *tremuloides* × *grandidentata* and *alba* × *grandidentata* clones survived, but a number of the *canescens* × *grandidentata* perished; whether this failure was due to lack of hardiness or poor suckering ability is not clear. In any case such physiological variation was anticipated on the basis of the high degree of morphological variation previously noted for this progeny.

Growth vigor and resistance to die-back caused by *Napicladium* sp. was selected for during the 1938–39 seasons. This resulted in removal of all the *tremuloides* × *grandidentata* hybrids. These plants showed medium to poor growth and great susceptibility to die-back, but, on the other hand, showed a fair degree of resistance to *Melampsora* rust. Heimburger suggested that such extreme susceptibility of some hybrids to disease may be added to the mechanisms of isolation which maintain species differentiation, as described by Dobzhansky (76).

Subsequent development of the *alba* × *grandidentata* progeny gave promise of valuable varieties available directly for reforestation plantings. Well-marked hybrid vigor, easy propagation by root cuttings, at least of juvenile material, and well-defined resistance to *Melampsora* rust and *Napicladium* die-back were shown.

A number of other successful crosses

[8] Victorin (263) reported natural hybrids of these crosses in Quebec. Under normal conditions in Canada, however, *P. tremuloides* flowers about ten days before *P. grandidentata* but at about the same time as *P. alba* (88). Natural hybrids of the latter have been compared with the artificial and found to be identical (104). Tubeuf (260) reported natural hybrids between *P. alba* and *P. tremula*.

were later reported by Heimburger (104). Of genetic interest is the preliminary analysis of the mode of inheritance of branching habit indicated by the double cross: X *P. berolinensis* Dipp. × X "Northwest Poplar" (believed to be derived from natural crosses of *P. deltoides* Marsh. × *P. tacamahaca Michauxii* (Dode) Farwell var.). Since both parents in the cross are themselves hybrids of *Tacamahaca* × *Aegeiros* crosses, their progeny showed wide variation in vigor and leaf and stem characters. Of the 26 plants selected after discarding some dwarf seedlings, 12 showed the "excessive juvenile branchiness" character typical of X *P. berolinensis*, while the remaining 14 had the "clean stem" character. It was tentatively concluded that "excessive juvenile branchiness" is dominant to "clear stem" and may be transmitted to about one-half of the progeny in this cross. Branchiness is an undesirable character for the production of clear wood for various industrial purposes, but for shelterbelt material it is exceedingly desirable. For this reason the above cross was repeated on a larger scale, using other "Northwest poplar" material more resistant to *Septoria* canker and *Melampsora* rust.

Sweden. Hybridization studies in Sweden have been concerned chiefly with intraspecific crosses involving diploid and triploid forms of the native *P. tremula* and the especially promising *tremula* × *tremuloides* crosses which have been recently given wider scope by the introduction of ecotypes of wide geographic origin throughout the ranges of both species.

Johnsson (144) has noted that in comparative growth tests, F_1's of *tremula* × *tremuloides* have markedly superior vigor as compared to the native *tremula* and that the hybrids are not attacked by *Fusicladium radiosum* and only to a small degree by *Melampsora* rust. With respect to quality, however, progeny of some crosses of *tremula* élite trees are superior to the interspecific hybrids produced.

Nilsson-Ehle (181, 182) and Bergstrom (35) reported genetical and cytological studies of successful diploid × triploid crosses of *P. tremula*. The crosses were made primarily to determine the possibility of obtaining a tetraploid, since Müntzing (176) reported some giant pollen grains (with possibly the $3n$ complement of 57 chromosomes) produced by the wild triploid discovered in Skäne, Sweden. Interest in securing a tetraploid was prompted by the presumed feasibility of producing triploid seed at will by diploid × tetraploid crosses.

Of the approximately 100 plants obtained from one of the crosses, the majority were aneuploid (mostly hypotriploid), several were exactly diploid, one exactly triploid and one exactly tetraploid. All of the progeny proved to be healthy vigorous plants. The triploid and near-triploids, however, were distinguishable from the others by their extremely rapid height growth. The tetraploids fell somewhat below the triploid in vigor but had the largest leaves of all the progeny. The intermediate aneuploids showed poor development and were highly divergent in appearance, many dying at an early age.

These observations concur with Johnsson's (138, 139, 142, 143) studies of the progeny of diploid × triploid and triploid × triploid crosses of *P. tremula* which led him to conclude that triploidy represents the optimal degree of polyploidy in this species. The absence of tetraploid species or forms of *Populus* in nature, as far as is known, is cited as evidence that tetraploidy represents the limit of vitality in this genus.

Russia. Available reports of hybridization studies involving the poplars

which have been undertaken in Russia appear to be confined chiefly to the publications of Aljbensky (= Al'bensky or Aljbenskič) (2–6), Jablokov (123, 124, 126) and Bogdanov (46).

The practical objective of the work of Aljbensky has been directed to the production of fast-growing, drought-resistant hybrids for use in plantations and windbreaks in the steppes. Promising hybrids have been derived from a number of intra- and intersectional combinations involving European and Asiatic representatives, some of obscure identity, belonging to the sections *Leuce, Aegeiros* and *Tacamahaca* (4, 22). Selections from the following crosses, propagated by cuttings and tested for four to seven years at Kamyshin (ca. Lat. 50° N. Long. 45° E.), were rated best on the basis of their frost-, drought- and borer-resistance, ease of propagation by cuttings, and adaptability to a wide range of soils (5):

P. balsamifera × X *P. berolinensis*
P. moscoviensis × X *P. berolinensis*
P. pyramidalis × *P. simonii*
P. pyramidalis × *P. nigra*
P. alba × *P. bolleana*

The hybridization experiments reported by Jablokov indicate pre-occupation with the atavistic trend of genetic theory sponsored by the Lysenko school, and his work is thus concerned essentially with providing purported proof of the theory of the plasticity of the genotype under various environmental, especially nutritional, influences.

According to this worker (123), an analysis of progenies of crosses involving *P. alba* and *P. tremula* demonstrated that plants derived from one catkin on the mother tree of a particular cross were all uniform but differed significantly from plants derived from other catkins on the same tree. Significant differences were also claimed between progenies derived from crosses on trees in the open air and those derived from crosses of the same individuals using cut twigs in the greenhouse.

The influences of the Lysenko school are also noted in the description of the "vegetative hybrids" of Bogdanov (46), said to be derived from adventitious buds arising from callus tissue on stumps cut at the union of stock and scion or one-year old grafts. The interesting suggestion that such "hybrids" may be chimeras or very possibly tetraploids of either stock or scion tissue is not noted by the author.

Mode of Inheritance. Data on the mode of inheritance of various characters in *Populus* are for the most part conspicuously lacking in the literature. This is largely due to the comparatively long time required for the plants to reach sexual maturity and the difficulties associated with the preservation of a sufficiently large sample of the F_2 to proved a statistical basis for study.

The dominance of certain characters in particular crosses has, however, been noted by various authors. Thus the fastigiate branching habit of *P. nigra italica* tends to be transmitted as a dominant (204, 178, 279, 126). Heimburger (104) noted the dominance of certain branching characters, and Johnson (134) has reported in some detail on the inheritance of certain characters in F_1 and F_2 hybrids of a *P. alba* × *P. grandidentata* cross. Of interest in this regard are the data on height for the parents, F_1, and F_2 hybrids:

	Average Height at six years (Ft.)[9]
P. alba	14.0
P. grandidentata	11.7
F_1	17.6
F_2 (168 plants)	9.5

[9] Parental and F_1 clones propagated by cuttings; F_2 plants are seedlings.

This appears to be the first comparative evidence of F_2 vigor reported in the genus.

Studies of photoperiodic response in *P. tremula* in Sweden (14, 244) and Germany (285) have revealed that day length is a critical factor in growth. Sweden with its wide range in the high latitudes (ca. 56° N. to 69° N.) is especially well suited to such studies. Of considerable interest to tree breeders are results of investigations which indicate that northern (long-day) races of *P. tremula* are dwarfed when grown at the lower latitudes (short days) of southern Sweden. But conversely, plants of southern origin are stimulated in growth when transplanted to regions of long-day in the north. In these cases, presumably, the limiting factor for survival of such plants is their frost resistance.

Studies of crosses between northern, southern and geographically intermediate forms revealed that plants of northern and southern origin were uniformly homozygous for long- and short-day response, respectively, whereas plants from central Sweden were heterozygous for these factors. It was further demonstrated that long day response of northern forms was inherited as a dominant character (14, 244).

Selection for Disease Resistance

A considerable literature on varietal resistance to the various poplar diseases has accumulated in this country and in Europe. No effort has been made here to summarize this literature in detail but the following references may be consulted.

In this country the problems of selection for resistance to cankers (*Cytospora (= Valsa), Dothichiza, Hypoxylon, Nectria, Septoria, etc.*), die-back (*Cytospora, Napicladium*) and leaf rust (*Melampsora*) have been discussed or investigated by Detmers (71), Hartley (101), Schmitz and Jackson (216), Schreiner (218, 219, 221), Stout and Schreiner (239), Schreiner and Stout (227), Heimburger (103, 104), Bier (36–38), Gruschow (97), Davis (66), Waterman (269) and others.

Investigations of varietal resistance in Europe are reported by Day (67), Day and Peace (68), Delevoy and Boudru (69), Wettstein (279, 283), Koning (148–151), Pelkwijk (191), Vloten (266), Peace (189, 190), Jablokov (126), Nilsson-Ehle (180, 181), Régnier (200) and others. The essentially taxonomic work of Regnier (198, 199) in France, Houtzagers (116) in Holland, and Cansdale (55) in England, to which reference has been made before, represented initial ground work for further pathological investigations.

Vegetative Propagation

The ability to produce root suckers or stump sprouts under field conditions appears to be characteristic of most species of poplar, and with some species, in certain areas, such asexual methods may provide the principle means of reproduction.

Baker's (26) study of aspen (*P. tremuloides aurea* (Tidestr.) Daniels) in the central Rocky Mountains emphasizes the almost exclusive dependence on root suckering as a means of stand reproduction and extension in that area. A somewhat similar situation apparently prevails in other regions of the United States and in Europe for the native aspens, but periodic reproduction by seed at favorable intervals, especially following fire, very likely occurs rather frequently.

In contrast to the aspens, the "cottonwood complex" (*P. deltoides*) of the eastern United States places little reliance on suckering in nature. Reproduction is chiefly by seed on the favorable seed beds present along the

water courses where it occurs. The vigorous stump sprouting ability of young cottonwood is, however, exploited by the silviculturist (289).

The ability to root from stem cuttings under most conditions in high percentage without special treatment or handling appears to be characteristic of the species of *Tacamahaca* and *Aegeiros*. The members of the section *Leuce*, however, are in general considered to be "difficult" or "resistant" plants, and auxin treatment is usually required.

Snow (233) has demonstrated that dormant one-year old stump sprouts of individual trembling and largetooth aspen with which he worked could be rooted to the extent of 67 percent by treating with a 10 mg. per liter concentration of indolebutyric acid for 27 hours. Other treatments and results for individuals of other species of *Populus*, as well as other ligneous genera, have been summarized in a recent comprehensive review by Thimann and Behnke (251).

Although the aspens produce vigorous root suckers in nature, root cuttings as a rule prove an unreliable means of propagating older trees, even under nursery conditions. The cuttings usually produce abundant shoots, but high mortality at an early stage makes this method generally impractical.

A valuable technique for asexual multiplication of aspen and white poplars by stem cuttings which does not require auxin treatment has, however, been developed in Denmark (154, 155). Root cuttings are sprouted, and small soft-wood cuttings of the shoots are then made and rooted in sand. Such cuttings from aspen and gray poplar gave 80–100 percent rooting in 10–14 days.

Considerable inter- and intraspecific rooting variability has been noted by Canadian workers in the section *Leuce*. *P. alba* is in general said to be less resistant to rooting than the European or American aspens and shows noticeable interclonal variability in this character (83). Johnson (134) has indicated that the rooting capacity of *P. alba* is transmitted as a dominant character to its progeny in the cross *alba* × *grandidentata* but not in the cross *alba* × *tremuloides*. It was postulated that *tremuloides* carries an inhibitor for the *alba* rooting factor. Stout and Schreiner (239) observed that hybrids of the cross *deltoides* × *grandidentata* were characterized by the poor rooting character of the aspen. These workers, as well as Heimburger (104), have also reported clonal variation within the native cottonwood. Stout and Schreiner (239) stated that the rooting ability of some of their hybrids showed great improvement over rooting ability of either parents. The data upon which these conclusions were based or the specific cases involved were not, however, noted.

Thimann and Delisle (252) and Larsen (155) have discussed the vital influence of various circumstances, especially the age effect of the tree from which cuttings are taken, and several environmental factors (type of rooting medium, temperature, auxin concentration used, *etc.*), all of which exert a profound influence on the success or failure of root formation. On the basis of present evidence it is apparent that decisions with regard to the relative rootability of cuttings of various clones within or between species must be expressed in very general terms, unless careful duplication of treatment is used in the comparison.

It has been previously pointed out that one of the attractive features of this genus as experimental material for forest genetics and tree-breeding studies is closely associated with the ease with which most individually superior clones

may be propagated by twig or root cuttings. From a practical point of view rootable twig cuttings are more desirable than sproutable root cuttings because of their ease of handling, planting, *etc.* under forest plantation conditions. This situation has produced a rather profound influence on the direction that poplar breeding studies have taken in this country and has possibly obscured certain paths of research which might be profitably investigated.

With the exception of the Canadian work (103–105), little or no interest in the improvement of aspens has been shown in North America. Although the aspens in this country were early discredited and essentially ignored (205), commercial interest in their utilization, as previously pointed out, has steadily increased. The fact that a general notion prevails as to their poor rooting ability should not invalidate them as valued material for tree-breeding studies. On the basis of the apparent clonal variability in *P. alba* with regard to this factor, there seems to be no logical reason to discount the possibility of its occurrence in trembling or largetooth aspen. This information, however, must be gathered by a systematic analysis of variability in the wild population and not through the testing of taxonomic specimens in arboreta.

Even in the complete absence of cutting rootability it does not seem logical to ignore possibilities of improvement for the native aspens. If tested inter- or intraspecific crosses which yield a progeny containing a sufficiently high percentage of superior individuals are found, it would seem advisable to enquire into the possibility of using a direct seeding method on especially adaptable sites.

Burned-over areas in New England and the Lake States might be profitably managed in this manner. With the stand established by direct seeding, possibly using pelletized seed, it might be cut for pulp on a short rotation and then managed as coppice for a second rotation. The generally beneficial results to the soil associated with accumulation of hardwood litter might then make the site more suitable for the establishment of other desired species more demanding in their site requirements.

Heimburger (105) has pointed out that the chief disadvantages of the cottonwoods and balsam poplars for forestry use lie in their requirements for a soil which is rich by forestry standards and their special demands for careful site preparation. Aspens, however, may be grown on almost any level of fertility.

These observations are supported to some extent by the fact that the natural habitat of cottonwoods and balsam poplars are strictly low river-bottomland or swamp borders, whereas aspens are notably ubiquitous. Although capable of occupying a wide range of sites, there is no doubt that the quality of the aspen stand produced is closely correlated with site quality (297).

Silvics and Culture

The silvical characters of the various poplars and cultural practices used in forest plantations and natural stands in several countries have been described by various authors. Forestry Commission Bulletin No. 5 (10) and Leaflet No. 27 (23) of the Forestry Commission provide a useful summary of cultivation methods in Great Britain. French practice is discussed by Breton-Bonnard (49, 50), Stout (237), Guinier (99) and d'Alviella (7). Interest in poplar cultivation in the Netherlands is discussed by Houtzagers (118, 120) and Meeiker (170); in Norway by Barth (33); and in Germany and Switzerland by Leiber (163), Zircher (300), Barbey (31),

Wettstein (281, 283) and others; Bogdanov (43–45) discussed Russian methods. Weigel and Frothingham (270), Baker (24, 26), Williamson (289), Buttrick (54), Kittredge and Gevorkiantz (147), Bull and Muntz (53), Zehngraff (295–299), Stoeckler (235) and others have described silvicultural practices employed in the United States.

The important role of sod through its inhibiting influence on the successful establishment of poplar and other hardwood plantations has been studied and reviewed in considerable detail by Schreiner (224–226).

Chromosome Number

From lists of chromosome numbers and other reports published by various authors (40, 173, 86, 87, 253–256, 82, 39, 176, 177, 193, 169, 230, 64) it appears that the basic number in the genus *Populus* is 19.

On the basis of what he interpreted to be secondary association of chromosomes at metaphase I, Dillewijn (74, 75) concluded that *Populus* and possibly *Salix* are secondary polyploids with an original basic number of eight. Four of the original eight chromosomes, according to his hypothesis, have been triplicated, the other four duplicated, and the present number 19 was the result of a fusion of two chromosomes within one of the groups of three. Smith (230) gives further support to this hypothesis with the observation that trivalent association of chromosomes sometimes occurs in meiotic metaphase of certain diploid hybrids and quadrivalent formations in the triploid form of *P. alba*.

Of the approximately 45 species and forms of *Populus* which have been cytologically examined, the unreduced number of 38 chromosomes appears to be characteristic of most species, but naturally occurring triploid and experimentally produced tetraploid and aneuploid forms have been reported.

Blackburn and Harrison (40) reported *P. balsamifera* (= *P. deltoides* ?) as a probable tetraploid with an unreduced number of 76 chromosomes, but Meurman (173) and Smith (230) reported it as a normal diploid. As previously pointed out (231), however, it may also conceivably occur in the tetraploid form in nature.

Naturally occurring triploid or approximately triploid forms of three species in the section *Leuce* have been reported in recent years. Nilsson-Ehle (180), Blomqvist (42) and Melander (171) all reported finding strains of a "gigas" triploid ($2n = ca.\ 57$) form of *P. tremula* L. in the forests of Sweden. Later Nilsson-Ehle (181, 182) and Johnsson (138, 139, 142, 143) reported synthesis of triploids, tetraploids and various intermediate aneuploids from artificial triploid × diploid crosses.

Peto (193) has reported occurrence of triploid forms of *P. alba* L. and *P. canescens* (Ait.) Smith in Canada, and Dillewijn (73, 74) reported a naturally occurring form of *P. alba* in the Netherlands.

Diploid and Triploid Species Analysis

Most studies of diploid species (40, 176, 138, 82, 193, 230) reveal that meiosis is for the most part regular. Univalents at metaphase I have, however, been observed in various species by several workers. Smith (230) suggested that univalents observed in *P. laurifolia* and *P. adenopoda* were the result of precocious separation due to failure, or early terminalization of chiasmata rather than lack of homology.

Johnsson's (138) study of meiosis in 16 diploid *P. tremula* clones from various provinces in Sweden showed 12 which behaved quite normally, but four showed varying numbers of univalents

at metaphase I. Temperature changes in early spring during gametogenesis were suggested as a possible explanation. Pollen sterilities of these clones is shown in Table IV.

Meiosis in natural triploid clones having an unreduced chromosome set of 57 is in general characterized by considerable abnormality (176, 193, 138, 230). Variable numbers of univalents, bivalents and trivalents have been observed, and in one triploid *P. alba* clone studied, quadrivalent associations were noted (230).

Müntzing (176) and Smith (230) have concluded that on the basis of pairing relationships displayed at meiosis in the natural triploid forms of diploid species thus far reported, such triploids must be autotriploids resulting from the fusion of a diploid and haploid gamete. Precocious furrowing (230) or spindle fusion during the meiotic divisions (176, 75) may be responsible for the formation of microspores with an unreduced set of chromosomes.

Pollen sterility percentages for various diploid and triploid clones observed by several investigators are shown in Table IV.

The diploid clones, representing typically "pure" species of the genus, show a surprising range in pollen sterility. When these data are compared with chromosome pairing data for the same species (230), there is an obvious correlation between frequency of univalent chromosomes at metaphase I and pollen sterility. Thus in those species where univalents have not been observed, pollen sterility is low, two to seven percent; but in species showing univalents the pollen sterility is markedly higher, 19 to 45 percent. Smith (230), however, concluded that the univalent frequency was too low in these species to account fully for the sterility observed.

Pollen sterility of the several triploid clones which have been studied (Table IV) is remarkably low, in several cases being lower than some of the "pure" diploids. In the opinion of Peto (193)

TABLE IV

POLLEN STERILITY IN NATURAL DIPLOIDS AND TRIPLOIDS OF *Populus*

Species	*2n chromosome No.*	*Pollen sterility %*	*Authority*
P. acuminata	38	45	Smith (230)
P. adenopoda	38	19	"
P. alba	38	3	"
P. deltoides	38	2	"
P. grandidentata	38	2	"
P. koreana	38	12	"
P. laurifolia	38	40	"
P. nigra	38	3	"
P. nigra italica	38	4	"
P. Sargentii	38	7	"
P. tremuloides	38	2	"
*P. tremula**	38	30	Johnsson (138)
*P. tremula**	38	61	"
*P. tremula**	38	20	"
*P. tremula**	38	33	"
P. alba	57	23	Smith (230)
P. alba var. *aureointertexta*	57	6	Peto (193)
P. tremula	57	56	Müntzing (176)

* Noticeably aberrant individuals from a group of 16 studied.

the genetically unbalanced pollen grains undergo early deterioration and consequently are not included in pollen sterility counts. This explanation may be criticized on the basis of Johnsson's (138, 139, 142, 143) and Bergstrom's (35) results which demonstrated that triploid × diploid and triploid × triploid crosses of *P. tremula* yielded progeny with intermediate chromosome numbers, which would seem to imply that in this species, at least, some unbalanced pollen grains are capable of survival.

F_1 Hybrid Analysis

Studies of meiosis in F_1 hybrids of *Populus* have been conducted by Peto (193), Dillewijn (75) and Smith (230). The comprehensive investigations of the last named, involving ten natural and 21 artificial[10] hybrids, revealed that the common meiotic abnormalities encountered were asynapsis which resulted in subsequent lagging of chromosomes at anaphase I and II, inversion bridges caused by structural differences, and various abnormalities in cytokinesis following the second division which gave rise to dyads, triads and microspores in excess of four.

On the basis of Darlington's (63) classification of hybrids, Smith concluded that the interspecific hybrids in *Populus* conform to the class called "undefined structural hybrids", *i.e.*, those resulting from the union of gametes with undefined structural differences between their chromosomes which are either too slight or too numerous to be detected.

In the 31 hybrids investigated by Smith (230), as well as those studied by Peto (193) and Dillewijn (75), univalent chromosomes were present in varying numbers in all. Smith found a close correlation between the occurrence of univalent chromosomes and supernumerary spores. A positive correlation (r = .88) was also observed between frequency of univalent formation and pollen sterility. Thus, of the 31 hybrids studied, the highest pollen sterility (80% was observed in X *P. Woobstii* (= *laurifolia* × *tristis*) and the lowest (5%) in the un-named hybrid derived from the double cross: X *P. charkoviensis* × X *P. plantierensis*. In the former case an average of 14.24 univalents per cell were observed, and in the latter case univalents averaged 0.28 per cell.

In practically all of the hybrids studied by Smith, varying numbers of inversion bridges were observed at anaphase I. This is the first report of structural hybridity in the genus, although Dillewijn (75) had previously reported attenuated chromatin strings between anaphase I plates in X *P. robusta*. Smith concluded that pollen sterility in poplar hybrids is probably traceable to genetic, structural and environmental factors, but which exerts the greater influence cannot, on the basis of present evidence, be stated.

Some data of peculiar interest to forest geneticists, reported by Smith (230), concern the influence of age on mutation rate and the possibility that trees or clones of old age may accumulate gene mutations or structural changes in their chromosomes. Theoretically such accumulations in old trees or clones should be detectable by their greater pollen sterility.

In support of this hypothesis it is demonstrated that the 21 artificial hybrid clones of comparatively recent origin (*circa* 1925) that were studied had pollen sterility percentages ranging from five to 40, with an average of 19.7. This, incidentally, corresponds quite closely with the pollen sterility found in the "pure" species studied. The ten natural hybrid clones, however, of much older origin, showed a wider range in

[10] Produced by Stout and Schreiner (239).

sterility (six to 80 percent) and a noticeably higher average of 46.7 percent. Certain of these data are reproduced here without alteration (Table V) from the work of Smith (230).

Speciation

On the basis of his extensive cytological studies of species and hybrids in *Populus*, Smith concluded that species differentiation in this genus has resulted primarily from isolation of a geographic, edaphic and physiological nature. Poplar species are thus examples of "ecospecies", as defined by Turesson (261), *i.e.*, uniform types between which crossing is possible with a relatively high degree of fertility, but which commonly are prevented by isolating barriers from doing so.

TABLE V

A COMPARISON OF CERTAIN NATURAL AND ARTIFICIAL INTERSPECIFIC HYBRIDS OF *Populus* IN REGARD TO DATE OF ORIGIN, UNIVALENT CHROMOSOME FORMATION AND POLLEN STERILITY (230)

Name or No.	*Parentage*	*Probable date of origin*	*Univalents per cell*	*Percentage of sterility*
Natural hybrids				
X *P. berolinensis*	*P. laurifolia* × *P. n. italica*	1870	5.30	57
X *P. canadensis Eugenei*	*P. deltoides* × *P. nigra*	1850	4.92	63
Artificial hybrids				
OP-67*	*P. nigra* × *P. laurifolia*	1925	1.00	16
OP-114*	*P. nigra* × *P. trichocarpa*	1925	0.80	23

* Hybrids produced by Stout and Schreiner.

The evidence in support of this hypothesis is based on the following points:

1. Species of one section cross readily with others under artificial conditions where geographic, edaphic or physiological barriers have been removed.

2. F_1 hybrids of such crosses are relatively fertile; in any case, none is completely sterile. Therefore, in the absence of geographic, edaphic or physiological barriers, backcross generations would permit an exchange of genes between the populations of the two species involved.

3. Although structural and genetic differences, as indicated by inversion bridges and asynapsis, are present in F_1 hybrid chromosomes, the functional fertility of these hybrids discounts genetic or structural chromosomal isolation.

4. Although relatively fertile autotriploid forms of the section *Leuce* occur in nature, they are unable to preserve their identity by sexual means. Numerical chromosomal isolation is thus ruled out as a factor in speciation. (However, if *Populus* is indeed a secondary polyploid it must be conceded that polyploidy played an important part in the ancestral differentiation of the genus.)

Sex

The dioecious nature of *Populus* has attracted the interest of investigators concerned with the study of sex mechanisms in plants. Blackburn and Harrison (40) first reported an heteromorphic bivalent in male clones of *P. tremula* and *P. nigra*. Meurman (173) also observed an heteromorphic pair in males of several other species and concluded that sex in *Populus* is determined by an XY mechanism similar to that prevailing in most animals.

Subsequent studies by various workers have confirmed these observations or criticized them. Müntzing (176) has pointed out that some intersexual forms should be found in the natural triploids if they originate from the union of haploid and diploid gametes. No such intersexes have been reported. Peto (193) found no consistent evidence of heteromorphic pairs, and Smith (230) was of the same opinion.

A point of considerable theoretical and practical interest to tree breeders interested in the genus *Populus* relates to the possibility that certain secondary sexual characters may distinguish the sexes.

C. S. Larsen (158) has discussed the problem briefly with respect to certain dioecious ligneous genera, citing his own observations and those of various other European botanists. This investigator, for instance, studied natural stands of *Juniperus communis* and found a positive correlation between sex and growth habit independent of site: the female trees being comparatively broad, the males being more slender (156).

The same author (158) has cited the observations of Correns (61) who noted that male specimens of *Ginkgo biloba* and *Taxus baccata* are on the average larger; and, with reference to the ginkgo, Grier (94) has also reported an apparent correlation between sex and growth habit.

Houtzagers (120), with reference to the ash planted in Holland, says: . . . "of this species (*Fraxinus excelsior* L.)—which, however, is not purely unisexual and dioecious—the male specimens g e n e r a l l y grow better and straighter than the female specimens do".

Evidence of the occurrence of secondary sex characters in poplars is confined for the most part to cultivated forms, little attention having yet been directed by silviculturists or geneticists to the analysis of natural stands. In the case of the widely planted ornamental variety of the black poplar, Lombardy poplar (*P. nigra italica* Muench.), it is the male form which is most favored by horticulturists. This preference is undoubtedly traceable to the markedly columnar habit of this sex, the females having a broader crown.

Larsen (158) reported sexing of an ornamental planting of grey poplar (*P. canescens* (Ait.) Sm.) in Denmark and found only "male individuals with the exception of a single female tree, which differed much from the others in being considerably smaller and of another shape of crown". The same author (158) has pointed out that early cultivation of *P. trichocarpa* in Sweden was attended with good results, whereas plantings of the same species in the State of Anhalt, Germany, were less satisfactory. It has been suggested that the explanation might be that in the former case it was a male clone which had been introduced, and in the latter case a female.

Other less specific evidence may be cited which is suggestive of sexual dimorphism in the genus. It is of interest, for instance, to note that of the eight commonly planted poplar clones in Holland, as listed and described by Houtzagers (116), only two (25%) are females.[11] A preference for males in this case may, however, be traceable to the fact that the "cotton" is irritating to the nostrils of cattle, and Dutch farmers may thus discriminate against female trees.

[11] Clones of both sexes of the native *P. nigra* L. are apparently planted without preference as to sex, and consequently this species is not here included. Of the eight forms considered, four are represented exclusively as male clones and two are "chiefly male, though some female trees are found".

Analysis of data on the sex of a number of poplar clones selected in the fall of 1947 by the present author (188) in collaboration with Dr. Helge Johnsson of the Swedish Forest Tree Breeding Institute, Ekebo, Källstorp, Sweden, reveals that out of 76 clones (including *tremuloides, grandidentata, tacamahaca, trichocarpa* and *deltoides*) bearing flower buds, only 18 (23.7%) proved to be females. Since the trees were selected on the basis of their apparent health, vigor and good stem form as compared with their associates in various stands throughout the United States and Canada, it might be concluded tentatively that a positive correlation exists in this genus between maleness and these desirable economic characters.

Such a conclusion is, however, confounded by the empirical observations of Baker (26) with respect to the apparent sex ratio in aspen stands of the central Rocky Mountains. This worker noted that "the staminate trees are much more frequently found than the pistillate, which are very rare indeed", and Williamson (289) makes a similar observation with regard to the cottonwood stands of the Mississippi valley. If such aberrant sex ratios are indeed characteristic of natural stands, it is apparent that samples of wild populations such as noted above cannot in themselves be used as evidence of male superiority. But if a sex mechanism for *Populus* is postulated that would theoretically result in a 1 : 1 ratio of the sexes, we must conclude that the presumed aberrancy of such ratios in favor of males in nature must be traceable to some sex-associated survival factors such as vigor, disease resistance and hardiness.

Although the evidence at present available is in no way conclusive, it is at least strongly suggestive that sexual differences within the genus do exist, and that such important characters as growth habit, stem form, disease resistance and vigor appear to be associated with the male sex. It is needless to point out that such a correlation, if confirmed, would be an invaluable aid to the selection efforts of tree breeders and silviculturists interested in the genus *Populus.*

Summary

Except for one tropical species in east Africa, *Populus* is native of the north temperate zones of Europe, Asia and North America. Of the approximately 30 species now known, only four are native in Europe and western Asia, the remainder being about equally divided between North America and eastern Asia.

Classification and nomenclature in the genus are confused and inadequate to describe the wide range of variability which has accumulated chiefly through ecotypic isolation and natural and artificial hybridization. This situation has led to interminable confusion in the literature. The only adequate solution appears to be an internationally cooperative agreement on nomenclature which will be based on a system of clonal names or numbers.

Studies of wild variability as a means of selecting superior forms for direct use or as parents for progeny tests and further breeding has been given considerable attention in Europe. In North America and Asia, however, very little work has been directed to this basic problem.

Much effort has been expended in the process of performing interspecific crosses, especially with species of the sections *Leuce, Tacamahaca* and *Aegeiros.* These studies have revealed a wide range of compatibilities, and suggest promising combinations for more intensive work in the future. It may be anticipated that such future studies will

be more critically concerned with the genetic quality of the individual parents concerned than has been the practice heretofore. It appears likely that the valuable North American and Asiatic species of the section *Leuce*, early discriminated against and essentially ignored because of their reputation as poor rooters, will attract more interest from tree breeders.

Very little intraspecific hybridization has been carried on within the North American and Asiatic poplars, but on the basis of German and Swedish results in this field such investigations hold promise of yielding valuable results.

Rather extensive cytological studies have been conducted by a number of workers in *Populus*. Representatives of most species and many hybrids have been examined, but the sampling of wild populations outside of Europe has been very inadequate. The diploid number of chromosomes for most individuals of the various species examined is 38, but natural triploid forms are of relatively common occurrence in the European species of the section *Leuce*. There seems to be little doubt that triploidy is the natural limit of heteroploidy in the genus.

Most poplar hybrids display a comparatively high degree of fertility, and primarily on the basis of this fact it has been postulated that edaphic, geographic and physiological isolating mechanisms have been chiefly concerned with the process of speciation in the genus.

Some empirical observations are assembled by the author which suggest that a positive correlation may exist between maleness and such economically desirable characters as vigor, disease resistance and good stem form in the poplars.

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Correction

ECONOMIC BOTANY, Vol. 2, page 107, para. 2, requires correction, since the work of Tschermak in 1918 on heterosis in tomatoes referred to there is antedated by that of R. Wellington reported in New York Agr. Exp. Sta. Bull. 346, 1912, and by that of H. K. Hayes and D. F. Jones in the Annual Report, Conn. Agr. Exp. Sta., 1916. Professor Tschermak, who, of the three rediscoverers of Mendel's principles, alone survives, writes that he probably was one of the first to obtain tentative evidence of heterosis in tomatoes and that his successor, Professor Dr. Fr. Frimmel, published evidence confirming it in Zeits. Pflanzenzüchtung **10**: 453–466. 1924–25.—J. W. Lesley.

Utilization Abstract

Waxes and Fats from Sugar Cane. In 1940, 26 million pounds of vegetable waxes were imported into the United States, and from January through September of 1947 such imports consisted of 8,444,000 pounds of carnauba, 8,371,000 pounds of candellila and 1,637,000 pounds of ouricouri, the three most important commercial waxes. [Carnauba wax is scraped from the leaves of *Copernicia cerifera,* a palm tree native to Brazil and other parts of tropical South America; candelilla wax is removed by hot water or solvents from the stems of *Pedilanthus Pavonis* and *Euphorbia antisyphilitica,* desert shrubs of Mexico and Texas; and ouricouri is similarly obtained from the leaves of *Cocos coronata,* a species of palm in northeastern Brazil.

Annual world production of vegetable waxes amounts to about 35 million pounds, approximately 80% of which is consumed in the United States in the manufacture of waxes for floors, shoes, furniture, automobiles, boats and aircraft, and in other items, including carbon paper and printing inks, textile water repellents and fruit and vegetable coatings, moulding compositions and phonograph records, and a score of less important products.

The many industrial uses of waxes have led to a search for other sources, and attention is now being directed to the possibilities of commercial production of wax from sugar cane.

"Interest in sugar cane wax dates from the early years of the twentieth century. The first wax-recovery plant, established in 1916 in Natal, Union of South Africa, obtained the wax from sugar factory press cake by solvent extraction methods. Thousands of tons of wax were produced during its ten-year period of operation. The operations ceased, apparently, when normal distribution and prices of the usual commercial waxes were re-established after World War I. But due to the scarcity of vegetable waxes during World War II and the post-war high costs, the interest in sugar cane wax has again revived. Not long ago the Cuban American Sugar Company and S. C. Johnson & Son, Inc., built a plant for the extraction of crude sugar cane wax from press cake at the Cuban American Sugar Company's plant in Cuba and have been producing sugar cane wax in commercial quantities for over a year."

This cuticle wax is obtained from the press cake of sugar cane, after extraction of sugar, and varies from 1% to 22% by dry weight of the cake. The crude wax is extractable by a number of solvents, including benzene, methyl and rectified spirits, acetone, certain esters, numerous aromatic hydrocarbons and petroleum solvents, and liquid sulphur dioxide and petroleum naphtha. After filtration or other means to obtain a clear extract, the crude wax is attained by evaporation of the solvent. (R. T. Balch, *Chemurgic Digest 7(7): 11. 1948*).